# FINAL REPORT

## Demonstration and Validation of GTS Long-Term Monitoring Optimization Software at Military and Government Sites

## ESTCP Project ER-200714

FEBRUARY 2011


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**14. ABSTRACT**
This ESTCP project was designed to demonstrate and validate use of the Geostatistical Temporal-Spatial (GTS) groundwater optimization software at three government demonstration sites: Air Force Plant 44 Site, Tucson, AZ (AFP44 site), Former Nebraska Ordnance Plant Site, Mead, NE (NOP site), and Fernald DoE Site, Ross, OH (Fernald site). Site operators/independent testers found GTS to be effective as an optimization tool and found the GTS interface highly usable, easy to navigate, and readily understood. Significant degrees of redundancy were identified at each demonstration site. The iterative thinning function in GTS recommended reductions in sampling frequency ranging from 50–75% across the three demonstration sites, while the spatial redundancy algorithm in GTS found degrees of spatial redundancy ranging from 16% to 40%. When the input data sets were essentially equivalent, GTS optimization results were shown to be highly reproducible when comparing results from expert users and independent mid-level analysts.

**15. SUBJECT TERMS**
long-term monitoring optimization (LTMO), statistics, geostatistics, sampling redundancy, groundwater, monitoring, optimization software, return on investment

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## ACKNOWLEDGEMENTS

The project team consisted of the following organizations:

- Air Force Center for Engineering and the Environment (AFCEE)
  - Philip Hunter, P.G.
- MacStat Consulting, Ltd.
  - Kirk Cameron, Ph.D.
- Science Applications International Corporation (SAIC)
  - Robert B. Stewart
  - Michael Kenny

AFCEE led the project, including management of project funds, schedule, and deliverables. MacStat Consulting was responsible for developing the GTS algorithm, coding the statistical routines in R for use in the GTS software, and performing expert GTS analysis of the data from each demonstration site. SAIC assisted with project deliverables and management, and developed the overall GTS executable, including coding the graphical user interface (GUI), MatLab code, and all data structures and graphics.

The principal author of this report was Dr. Kirk Cameron, with editorial assistance from Philip Hunter and Robert Stewart. We would also like to acknowledge the participation of the following individuals:

- Dave Becker, U.S. Army Corps of Engineers, Environmental and Munitions Center of Expertise (Omaha) — Mr. Becker participated in numerous conference calls; provided technical support, testing of GTS, and review of reports; coordinated the participation of the former Nebraska Ordnance Plant site (NOP); and performed an independent GTS analysis of data from NOP.
- Jon Atkinson, AFCEE — Mr. Atkinson also participated in conference calls; provided technical support, testing of GTS, and review of reports; and performed independent MAROS and GTS analysis at AF Plant 44.
- Robert L. Johnson, Argonne National Laboratory (DoE) — Dr. Johnson coordinated data retrieval, screening, and packaging of data at the Fernald DoE site; provided technical support and testing of GTS; and performed independent GTS analysis of the data from Fernald.
- John Quinn, Argonne National Laboratory (DoE) — Dr. Quinn performed beta testing of GTS, participated in conference calls, and performed independent GTS analysis of data from the Paducah, Kentucky DoE site.

## LIST OF ACRONYMS

| | |
|---|---|
| 1,1-DCE | 1,1-Dichloroethene |
| 1,1,1-TCA | 1,1,1-Trichloroethane |
| 2,4-DNT | 2,4-Dinitrotoluene |
| AFCEE | Air Force Center for Engineering and the Environment |
| AFP44 | Air Force Plant 44 |
| ASCII | American Standard Code for Information Interchange |
| bgs | Below ground surface |
| BRAC | Base Realignment and Closure |
| bw | Bandwidth |
| CAS | Chemical abstracts service |
| CDF | Cumulative distribution function |
| CERCLA | Comprehensive Environmental Response, Compensation, & Liability Act |
| COC | Contaminant of concern |
| CSM | Conceptual site model |
| CV | Coefficient of variation |
| DCDF | Declustered cumulative distribution function |
| DERP | Defense Environmental Restoration Program |
| DoD | Department of Defense |
| DoE | Department of Energy |
| DPT | Direct push technology |
| EPA | Environmental Protection Agency |
| ERPIMS | Enviromental Restoration Program Information Management System |
| ESTCP | Environmental Security Technology Certification Program |
| gpm | Gallons per minute |
| GTS | Geostatistical Temporal-Spatial optimization software |
| GUI | Graphical user interface |
| GWTP | Groundwater treatment plant |
| HHRA | Human health risk assessment |
| HTML | Hypertext markup language |
| IT | Information technology |

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|---|---|
| LTM | Long-term monitoring |
| LTMO | Long-term monitoring optimization |
| LWQR | Locally-weighted quadratic regression |
| LZ | Lower zone |
| MAROS | Monitoring and Remediation Optimization Systems |
| MC | Methylene Chloride |
| MCL | Maximum contaminant limit |
| MDL | Method detection limit |
| MILR | Multiple indicator local regression |
| MMR | Massachusetts Military Reserve |
| MNA | Monitored natural attenuation |
| NOP | Former Nebraska Ordnance Plant |
| NPL | National Priorities List |
| OSS | Office of Strategic Services |
| OU | Operating unit |
| ppb | Parts per billion |
| PQL | Practical quantitation limit |
| QA | Quality assurance |
| QC | Quality control |
| QLR | Quantile local regression |
| RCRA | Resource Conservation Recovery Act |
| RDX | Hexahydro-1,3,5-trinitro-1,3,5-triazine |
| RL | Reporting limit |
| RMSE | Root mean squared error |
| ROI | Return on investment |
| RPO | Remedial process optimization |
| SAIC | Science Applications International Corporation |
| SGZ | Shallow groundwater zone |
| TCE | Trichloroethylene |
| TNB | 1,3,5-trinitrobenzene |
| TNT | 2,4,6- trinitrotoluene |
| µg/L | Micrograms per liter |
| UZLU | Upper zone lower unit |

| | |
|---|---|
| UZUU | Upper zone upper unit |
| VOC | Volatile organic compound |
| VSP | Visual Sample Plan |

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# EXECUTIVE SUMMARY

The primary objective of this ESTCP project was to demonstrate and validate use of the Geostatistical Temporal-Spatial (GTS) groundwater optimization software, developed by MacStat Consulting and Science Applications International Corporation (SAIC) for — and under the auspices of — the Air Force Center for Engineering and the Environment (AFCEE), at three DoD and DoE sites. The three demonstration sites were as follows:

- Air Force Plant 44 Site, Tucson, AZ (AFP44 site)
- Former Nebraska Ordnance Plant Site, Mead, NE (NOP site)
- Fernald DoE Site, Ross, OH (Fernald site)

The GTS software demonstrated in this ESTCP project offers a set of tools for long-term monitoring optimization (LTMO) and consists of five major modules:

- **Prepare** imports analytical and water-level data, imports site boundaries and shape file overlays, and enables data management via a) an internal SQLite database, b) creation of analysis variables, and c) identification of outliers.
- **Explore** allows for basic statistical exploration via data summaries and graphs, analysis and ranking of contaminants based on optimization potential, and identification and analysis of multiple vertical aquifer horizons.
- **Baseline** displays initial groundwater monitoring network status, fits non-linear baseline trends via locally-weighted quadratic regression (LWQR), displays trend maps, builds spatial models via bandwidth selection, computes and displays potentiometric surfaces, and constructs and displays concentration-based plume basemaps using quantile local regression (QLR).
- **Optimize** allows for both temporal and spatial optimization. Temporal optimization in GTS consists of two components: 1) *temporal variograms* applied to groups of wells, and 2) *iterative thinning* of individual wells. More than one temporal optimization method allows for flexible handling of the kinds of data available at different installations. Spatial optimization within GTS consists of: 1) searching for statistical redundancy via mathematical optimization using the GTSmart algorithm; 2) determining optimal network size with the aid of cost-accuracy tradeoff curves; and 3) assessing whether new wells should be added and where (i.e., *network adequacy*).
- **Predict** allows import and comparison of new sampling data against previously estimated trends and maps. Two options include trend flagging and plume flagging to identify potentially anomalous new values.

To support the Optimize module, GTS also includes a separate, stand-alone Excel spreadsheet Cost Comparison Calculator, in order to realistically calculate the financial benefits of implementing a GTS-optimized sampling program, as well as return on investment (ROI).

Some of the advantages of the v1.0 release of GTS demonstrated in this project include the following:

- Substantial projected annualized and life-of-project cost savings from implementing a GTS-optimized program, in the range of 30%-60%. Return on investment for a GTS-optimized monitoring program is generally one to two years or less.
- Equally applicable to site-specific plumes, and unit-wide or base-wide studies involving multiple source areas, plumes, and monitoring conditions. This is because GTS does not require or utilize plume-specific configuration data, fate-and-transport models, or other hydrogeologic modeling information.
- Innovative exploratory tools for assessing data characteristics, ranking COCs for optimization potential, and analyzing multiple aquifer horizons. These tools can also assist in the identification and development of anthropogenic or background data sets.
- Sophisticated built-in graphics for data visualization, including contour mapping, complex trends, post-plots, and shape file annotation.
- Trend estimates derived from locally-weighted quadratic regression (LWQR), allowing for fitting of complex and/or seasonal time series data. All other currently available LTM optimization tools only offer fitting of *linear* trends, an assumption that does not match the reality of most LTM datasets.
- Semi-nonparametric surface map estimates made using quantile local regression (QLR), a smoothing technique not bound by the constraints of kriging. By design, QLR is made to handle skewed datasets as well as significant proportions of non-detects, data features ubiquitous to LTM networks.
- Automated redundancy searches employing mathematical optimization, both during temporal and spatial analyses. Spatial optimization is performed with a quasi-genetic algorithm unique to GTS, known as GTSmart.
- Use of multiple cost-accuracy tradeoff curves to gauge points of optimality. Defensible bias measures of statistical accuracy allow for rigorous analysis of potential tradeoffs.

Key results of the project are listed below:

- The GTS software was found to be easy to use and navigate by the testers and mid-level site analysts, even though none of these users was formally trained on the software. Because GTS v1.0 represents a major overhaul and upgrade to the previous beta-version, with a software architecture that was completely redesigned, a significant number of software bugs, logic flaws, and glitches were encountered during both internal and external testing of the software. By the end of project, no significant bugs or software errors remained.
- Graphical outputs in GTS were found to be quite helpful and attractive to users. These, combined with the unique exploratory data tools built in the software, were rated as one of its strong points.

- GTS was found to be effective as an optimization tool. Significant degrees of redundancy were identified at each demonstration site. The iterative thinning function recommended reductions in sampling frequency ranging from 50–75% across the three demonstration sites, while the GTSmart algorithm found degrees of spatial redundancy ranging from 16% to 40%. Further, GTS was run successfully at larger sites having more than 200 distinct well locations.

- Of the temporal optimization tools, iterative thinning was found to be superior in performance to temporal variograms. The variograms were easily computed, but yielded poor to mixed results. Overall, the results did not enable reliable or replicable estimates of optimal sampling intervals, since few variogram ranges (denoting points of optimality) could be identified at the test sites.

- A goal of this project was to enable users to perform water level-aided spatial mapping as an option in GTS. Internal testing of this feature led to mixed results and a decision not to include it in v1.0 of the software. However, as a by-product of this testing, GTS now includes the ability to create potentiometric surface maps of groundwater levels. Users found this to be a useful tool and visualization.

- When the input data sets were essentially equivalent, GTS optimization results were shown to be highly reproducible when comparing results from expert users and independent mid-level analysts. Except for the Fernald site, where the input data sets substantially differed, the optimized sampling intervals were identical on a site-wide basis at the other demonstration sites and differed only slightly when broken down by aquifer zone. Spatially, the levels of redundancy found using the same contaminants of concern (COCs) were very similar at both the AFP44 and NOP sites. Further, a locational analysis of which wells were flagged as redundant showed statistically significant similarity in common locations and spatial proximity.

- The trend and plume flagging tools in GTS were shown to be reasonably effective in flagging potentially anomalous measurements from a reserved subset of data from each demonstration site. And, because the reserved data sets were collected ‘close in time’ to the historical data — being observations from the next year of sampling — the projected (i.e., extrapolated) trends and plumes successfully predicted (i.e., bounded) over 90% of the new measurements. Nevertheless, the trend and plume flagging features may be too sensitive in flagging anomalies; further investigation indicated that perhaps only 30% of the trend anomalies and 65% of the plume anomalies were values actually deserving further investigation or verification.

- The network adequacy function successfully located areas of substantial mapping uncertainty at each demonstration site, and recommended coordinate locations for the siting of new wells. Because GTS cannot determine whether a suggested new location coincides with a physical obstruction or is unfeasible for other reasons, users were able to successfully override specific locations and to document those decisions visually on a post-plot of both existing and recommended locations.

Based on application of GTS v1.0 to the three demonstration sites during this project, the software has certain limitations that could be mitigated by future improvements. These include:

- GTS requires at least 15-20 well locations to properly perform spatial optimization, and at least 6-8 distinct sampling events per location in order to perform temporal optimization.
- GTS requires a number of input fields in ASCII text format in order to create a sufficient analysis database. Some users may find the directions for importing data and creating or augmenting databases within GTS more complicated than need be. The software would be improved if this process were streamlined and simplified.
- GTS does not offer sophisticated handling of radiochemical data, particularly measurements recorded with non-positive values (i.e., zeros or negatives). These data must first be converted to positive values, unless they represent non-detects with a known, positive detection or reporting limit. GTS could be improved by allowing a specific option for radiochemical data.
- Optimized sampling intervals from temporal variograms in GTS often do not match the optimized sampling intervals from iterative thinning using the same data. Further improvements to the temporal variogram algorithm may be needed, especially to account for sites with spatial trends that are actively changing over time.
- Cost-accuracy tradeoff curves in GTS are not interactive. Although the bias limits can be adjusted by the user, the spatial optimization must be completely re-run each time those limits are changed, in order to see the impact of the revised limits and to generate a new optimal network. The software could be improved by combining the current tradeoff curves into a single, weighted curve that would allow for interactive selection of different sampling plans by the user.
- There is no way in GTS v1.0 to batch print graphics. Since a GTS analysis typically generates a large number of statistical graphics, users may be frustrated with the inability to document graphical results outside the application. The software could be improved by enabling an option to do batch printing to popular image formats.
- The mathematical optimization algorithm in GTS is not a true genetic algorithm wherein portions of the binary string ‘DNA’ representing alternate network configurations are allowed to ‘mate,’ ‘mutate,’ and create ‘offspring.’ Instead, GTS does a ‘smart search’ through the space of potential network configurations, only selecting for testing those strings with interwell spacing comparable to the full network. The software might be improved by incorporating a true genetic algorithmic search.
- The Prepare Module may identify too many data records as ‘outliers’ at some sites, necessitating needless user review and override. GTS could be revised and streamlined by combining the temporal and spatial outlier searches into a single, improved algorithm that better accounts for local trend fluctuations.
- ‘Time slices’ in GTS — discrete, non-overlapping periods of sampling — are computed automatically, but are not adjustable by the user. The software could be

improved by allowing user input to define or adjust time slices to accord with site-specific remedial events or histories.

- The Predict Module readily identifies anomalous future measurements but may be too sensitive in flagging anomalies. GTS could be revised with improved trend and plume flagging routines, to better avoid flagging non-anomalous values.

The level of effort and computation time for applying GTS at the three demonstration sites are documented within this report, as well as a basis for estimating the costs of applying the software to other sites. Estimated cost-benefit analyses at each of the three sites are presented, along with projected return on investment (ROI) from implementing the GTS-optimized sampling plans. Estimated total cost savings compared to the baseline monitoring program ranged from 39% to 45%, with ROI ranging between 4 and 6 months. The specific well-by-well optimization recommendations computed by the ESTCP project team are listed in appendices to this report. A GTS users guide was finalized as part of this project and was submitted as a separate deliverable to ESTCP. The software and users guide are now available free for use by the public.

# 1.0 INTRODUCTION

## 1.1 BACKGROUND

The Department of Defense (DoD) has invested over $20 billion in environmental restoration through the Defense Environmental Restoration Program (DERP) to address restoration needs at active installations, formerly-used defense sites (FUDS), and in connection with base realignment and closure (BRAC) [1]. Across the agency, thousands of sites are engaged either in long-term maintenance, remedial investigations, and/or groundwater cleanup [2].

Since groundwater contamination is common at DoD sites, large monitoring networks comprising dozens, hundreds, or even thousands of wells are in place at many facilities, as required for long-term monitoring (LTM) by RCRA permits or under a CERCLA response. Frequently, the monitoring network has been installed either piecemeal or haphazardly over time, the result of changing goals and objectives, oversight by multiple contractors, changing subsurface conditions, and differing regulatory requirements. Relatively few sites have undergone a comprehensive optimization analysis, designed to identify an optimal network size and configuration, and to optimize the sampling plan and frequency of monitoring.

With moderate-size or larger monitoring systems, there can be redundancy in the number and placement of wells (*spatial redundancy*) and inefficient frequency of monitoring (*temporal redundancy*). There is also a risk that portions of the site may be too sparsely sampled (*under-coverage*) to adequately assess or characterize subsurface conditions. Optimization of existing monitoring systems aims at improving their effectiveness and reducing overall site cleanup costs, without losing information *critical* to satisfying regulatory and monitoring objectives, site characterization, or to measuring remedial success.

Redundancy and optimality in this project are treated as *statistical* concepts. Redundancy is premised on what can be estimated with sufficient accuracy when existing data are removed from the current system. The remaining data (the *reduced-data set*) must be used to reconstruct features or characteristics that were estimated from the *full-data set*. This may include the reconstruction of temporal features such as trends when selected sampling events are eliminated, or spatial features like surface maps when selected wells are removed. Redundancy is defined as the ability of the reduced-data set to reconstruct the original trend or map within certain bounds on probable error. Forcing reproduction of the original trend or surface map guarantees that an overall characterization of the plume (and its rate of change) can likewise be reconstructed using the reduced-data.

Of course, any measurement collected at a unique point in time and space provides some (statistical) information about the LTM network. Conversely, information is always lost when data are removed from the system. So judging an LTM network as “optimal” entails balancing a mathematical trade-off between this loss of information and the cost savings realized by not collecting/analyzing/measuring the additional data. An optimized system is one that entails — compared to the current system — a minor loss of (statistical) information, but a significant gain in cost savings.

Most current approaches to optimizing LTM network design typically rely on professional

engineering judgment as opposed to statistical logic. Engineering-based approaches often involve ‘piece-wise’ revamping of the monitoring network, instead of a more objective statistical evaluation. Facilities may change subcontractors periodically, resulting in a ‘patchwork quilt’ of LTM recommendations concerning well placement, network sufficiency, and sampling frequency. There can also be subtle pressure by contractors to justify and maintain LTM programs so as not to risk cuts in funding, as well as additional pressures by regulators to not reduce monitoring efforts for fear of losing vital data.

Due to these factors and the substantial costs associated with LTM, AFCEE has actively pursued testing of statistical optimization strategies for its LTM networks. The goal is to design a monitoring network able to capture necessary contaminant information — including the ability to meet DERP or regulatory objectives — but to do so at the lowest possible cost. One such strategy developed in coordination with AFCEE is the subject of this demonstration: the *Geostatistical Temporal-Spatial* (GTS) statistical optimization software tool [3].

GTS is designed to mathematically optimize LTM groundwater networks. Version 1.0 of the software has five modular components linked together in a wizard-type user interface. These components enable the following key tasks:

1. Data summary and exploration, including identification of chemical constituents best suited for optimization, and analysis of multiple aquifer horizons (should they exist);
2. Estimation of non-linear baseline trends and concentration-based surface maps;
3. Temporal optimization of sampling frequencies and spatial optimization of the number and locations of wells;
4. Identification of recommended locations for new wells, predicated on reducing mapping uncertainty; and
5. Tracking of new data against projected trends and concentration surfaces in order to flag potential anomalies, outliers, or recent plume changes.

GTS also includes a separate cost-benefit estimating tool designed to realistically quantify the potential savings and return on investment (ROI) achievable by implementing an optimized sampling program.

## 1.2 OBJECTIVE OF THE DEMONSTRATION

The primary objectives of this project included the following:

1. **To promote** widespread adoption of statistically-based optimization efforts across DoD and government facilities involved in LTM, especially through the public release of GTS v1.0.
2. **To accelerate** the transfer and usage of GTS as a viable software technology to analysts and site managers desiring to physically optimize their LTM networks, by improving and completing the *user interface*. This project will enhance the functionality of GTS, improve performance, and make the tool more user-friendly for effective transition to potential users.
3. **To incorporate**, as an automated feature, simple, site-specific flow regime

information into the GTS mapping capability, by allowing the inclusion of water level data for one or more sampling events.

4. **To demonstrate** the applicability, usability, and effectiveness of an enhanced GTS software interface at sites representing multiple branches of DoD. The fully-functional interface will be tested by the target audience: mid-level analysts with some statistical and geostatistical experience and a hydrogeologic background, to ensure that such analysts can arrive at similar optimization results to those generated when statistical/geostatistical experts evaluate the same data using the same software.

## 1.3 REGULATORY DRIVERS

There are no regulatory issues directly associated with this project, although the initial impetus for GTS was to more efficiently and cost-effectively meet regulatory requirements for LTM under both RCRA and CERCLA. Application of the software demonstrated in this project is intended to improve the efficiency and assessment of the monitoring well networks and data that are collected during LTM, which will ultimately address regulatory objectives and allow for improved communication between site stakeholders. Implementation of optimal sampling plans suggested for the demonstration sites is not within the scope of this project.

# 2.0 TECHNOLOGY

## 2.1 TECHNOLOGY DESCRIPTION

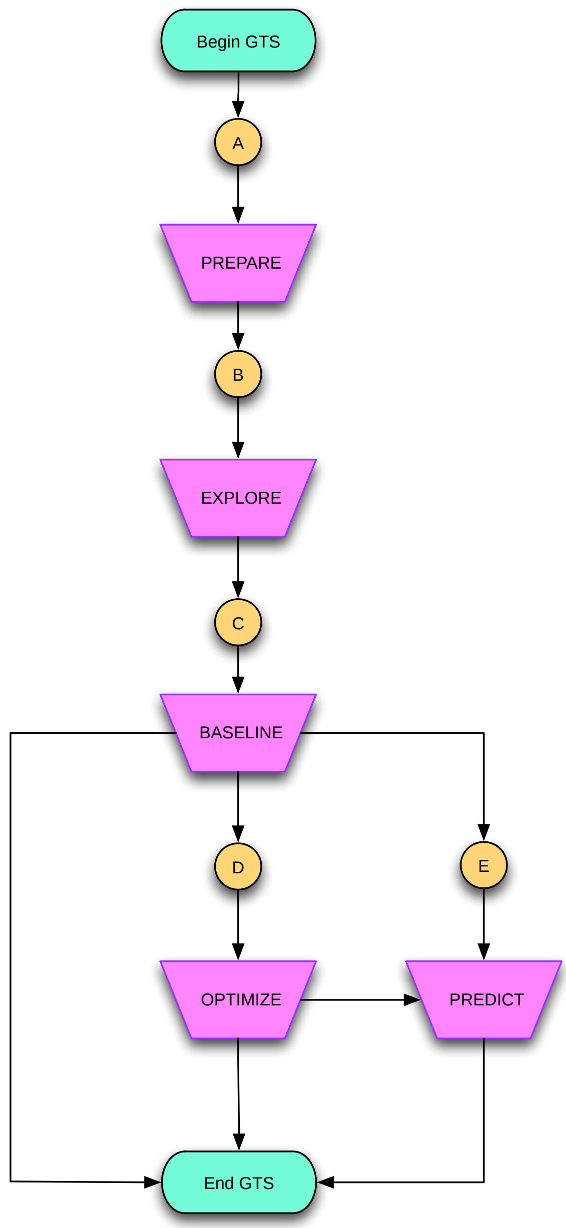
GTS is a set of freeware, desktop software tools, designed to perform mathematical optimization of LTM groundwater networks. GTS allows any contaminated site with the minimum number of well locations (i.e., 15-20 or more for spatial optimization) and distinct sampling events (i.e., 6-8 per well location for temporal optimization) to quickly (i.e., within a few to several days after electronic data gathering and preparation) analyze and develop an optimal groundwater monitoring plan. Not only can these plans be periodically reviewed and updated over the life of the facility, but they also allow for efficient use of sampling resources, providing the necessary analytic and sampling data for good regulatory and remedial decisions, while simultaneously eliminating unnecessary, superfluous, and/or wasteful data collection and expense.

Given the minimal data requirements, many sites undergoing LTM could potentially utilize the updated GTS software. This includes both larger and smaller sites due to the modular design of GTS and its ability to separately and independently optimize sampling frequencies and well locations.

The main GTS application (v1.0) consists of a set of five modules linked by a wizard-style graphical user interface (GUI). A schematic of the overall modular design is presented in **Figure 2-1**. The GTS distribution package also contains a separate Excel cost-benefit calculator spreadsheet for quantifying the resource savings achievable through implementation of a GTS-optimized sampling program.

The five modules in the main GTS application consist of Prepare, Explore, Baseline, Optimize, and Predict. All of these modules are built using open-source or license-free (to the user) runtime environments. R (www.r-project.org) is the statistical engine behind GTS, responsible for all statistical computations and estimates. The MatLab runtime environment (www.mathworks.com) is used to visually display maps, trends, and other statistical graphics. SQLite (www.sqlite.org) serves as an open-source database to house data imported into GTS and to store results. Finally, QT (http://en.wikipedia.org/wiki/Qt_(framework)) and C++ have been utilized to create the graphical user interface (GUI) with which users interact.

**Figure 2-1. Overall Modular Design of GTS**



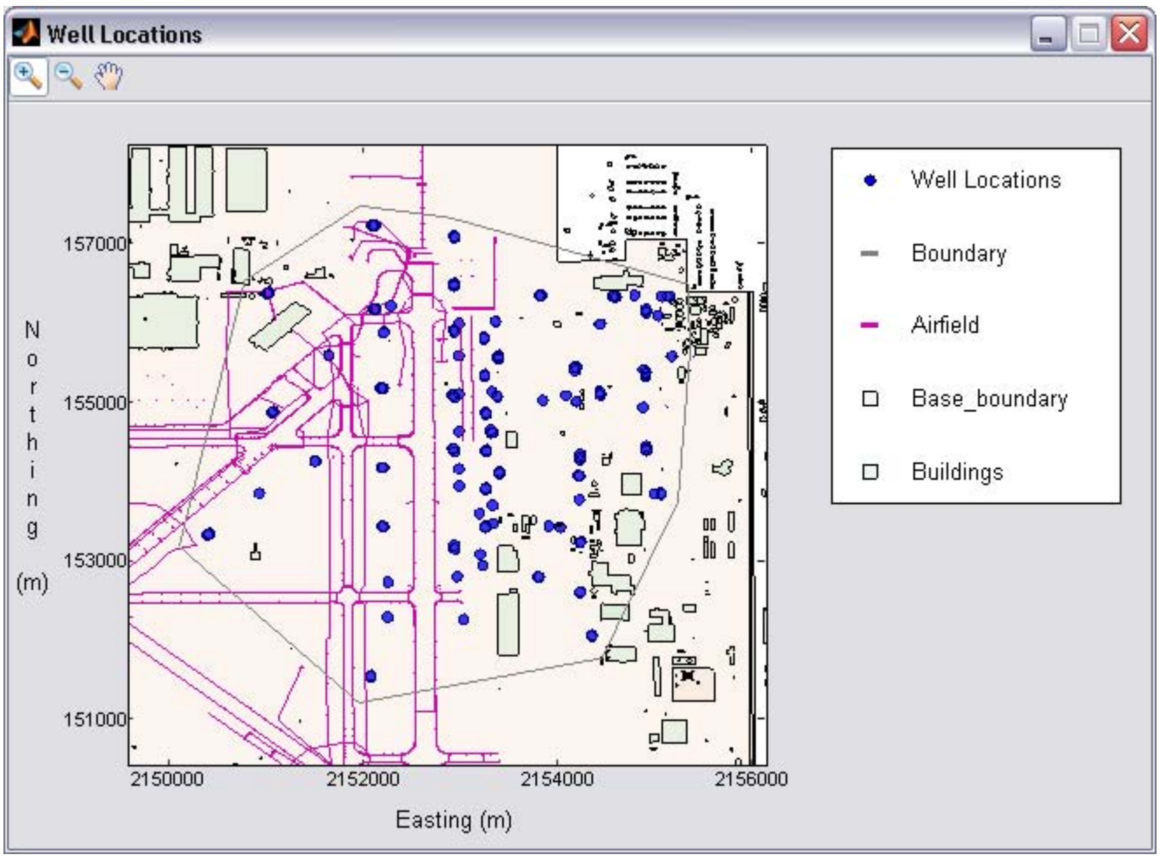

## Prepare Module

The Prepare module enables data import and simple data checking. [More detail about the Prepare module and any other GTS functionality may be found in the GTS Users Guide, which has been provided as a separate deliverable for this project.] Users can view a simple map of the well network, import shape files as GIS-overlays for visual annotation, and check for outliers in the imported database (see **Figure 2-2**). Of some importance, GTS only uses existing site data for its analysis. No geophysical or hydrogeologic modeling is required or utilized. A spatial

analysis usually requires at least 15-20 distinct wells to be useful, and a full temporal analysis requires at least 6-8 distinct sampling events of historical monitoring data per well. Other necessary information includes:

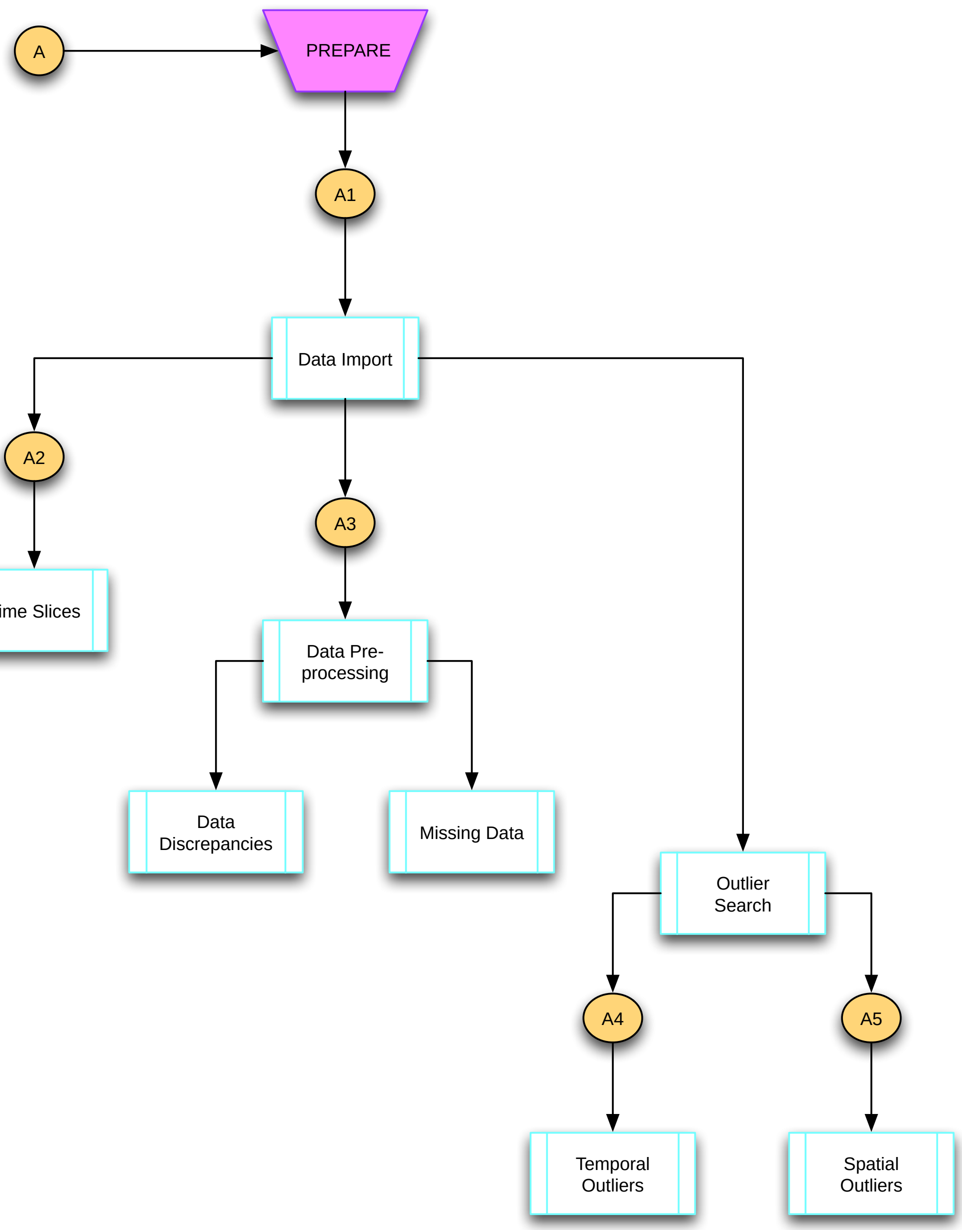
- Well ID and location
- Sample date
- Constituents of concern (COCs), concentration values, and reporting limits
- Screen depth, interval, aquifer zone
- Water level measurement data (optional)
- GIS data (ESRI Shape files) to represent key features of the site (optional)

**Figure 2-2. Example of Location Map in GTS**




GTS also creates a series of data-specific 'time slices' in this module. Each time slice represents a kind of 'snapshot' or 'window of time' where, by default, a large majority of the distinct wells has been sampled. By analyzing a series of such 'snapshots,' GTS assesses the degree of repeatability of its estimates of spatial redundancy; well locations are not classified as redundant unless they are redundant across a majority of the time slices, thus showing the results can be replicated over time. A schematic of logic and features of Module A is given in **Figure 2-3**.

**Figure 2-3. Schematic of Prepare (Module A) Logic**

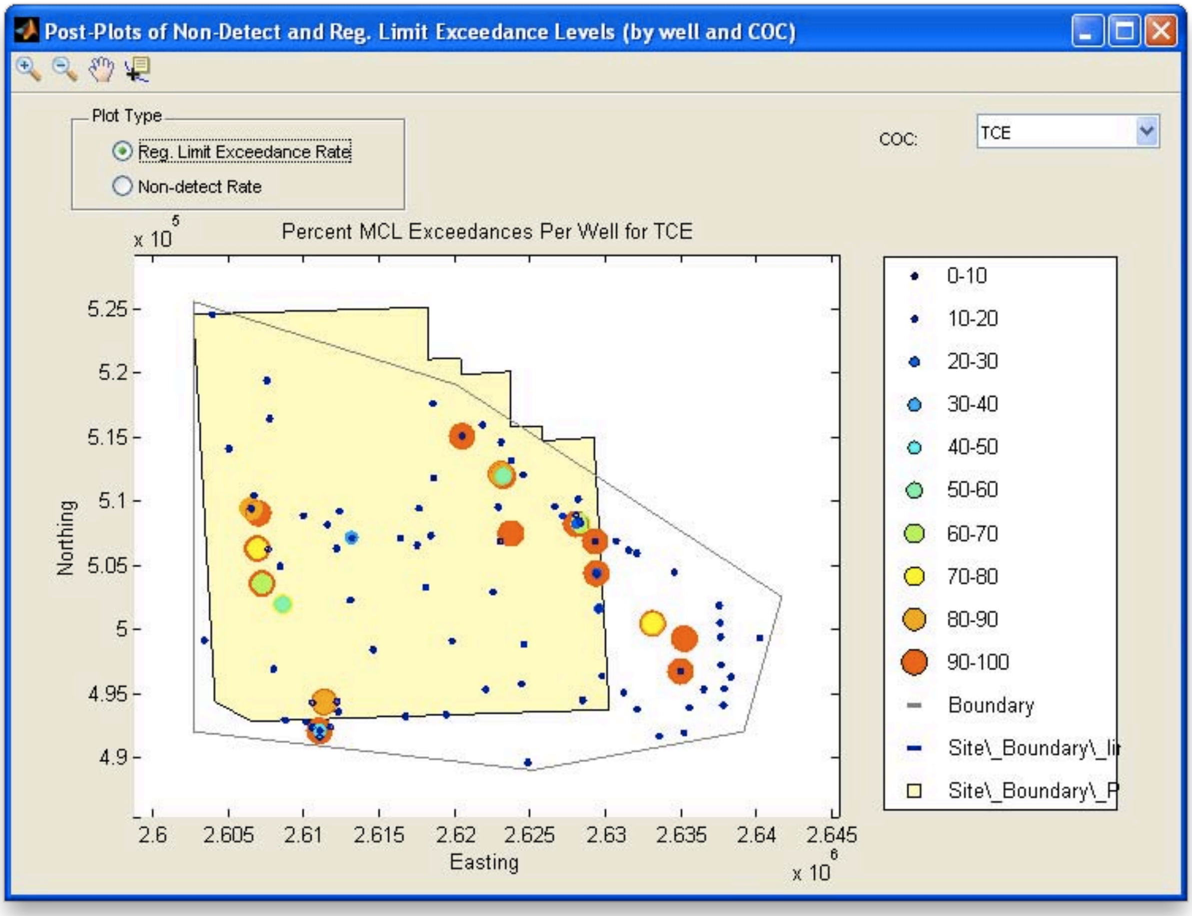



## Explore Module

The second GTS module enables the user to prepare simple data summaries and to examine exploratory graphs. These tools can be used in their own right to gain a 'feel' for data characteristics and/or data quality, through visualization of time series plots of individual wells, side-by-side boxplots of COC-specific concentration levels, and post-plots of concentration 'hot

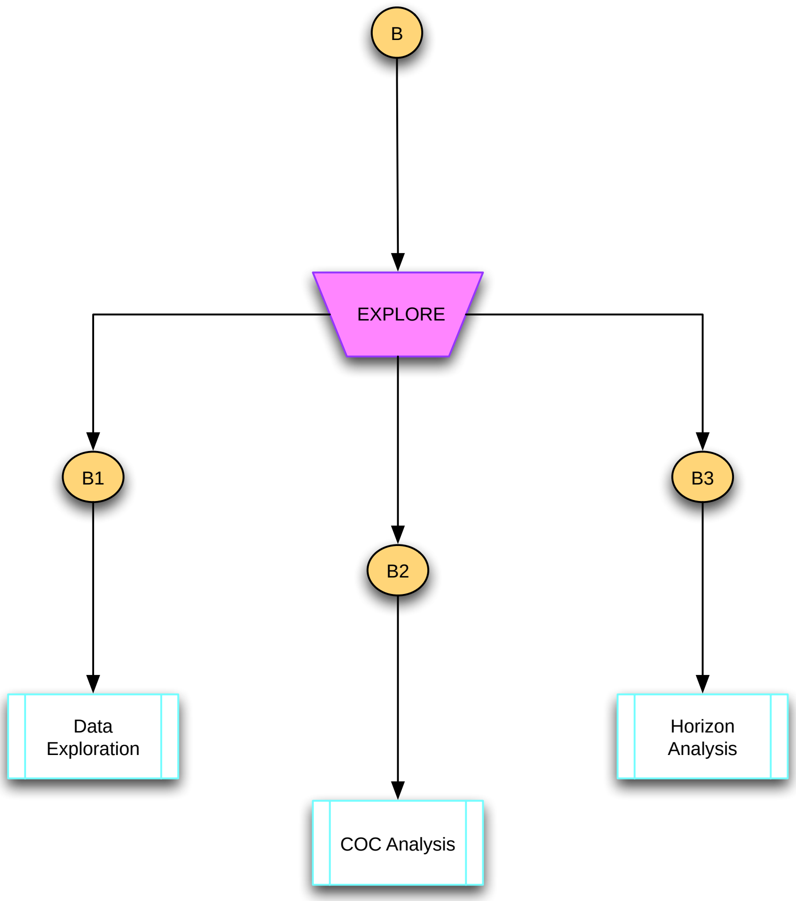
spots' and/or exceedances of regulatory levels (see **Figure 2-4**). An overview of the logic and features of Module B is given in **Figure 2-5**.

**Figure 2-4. Example Post-Plot of Regulatory Limit Exceedances**




The exploratory tools can also be used as part of a more extensive analysis to better prepare the data for optimization. GTS enables the user to rank COCs for optimization potential by examining frequency and location of detections and regulatory exceedances, toxicity and mobility factors, and key statistical indicators. Lower ranking COCs can then be excluded from further analysis. GTS also provides an analysis of vertical aquifer horizons. Horizon-specific variograms and boxplots can be examined to determine the degree of similarity in concentration levels and spatial correlation patterns. The user can decide to perform a simple 2D (i.e., two dimensional) analysis, grouping all horizons into a single horizontal plane, or instead a 2.5D (i.e., 'layer cake') approach, where each horizon is analyzed separately. Users can also delete or merge specific layers/horizons as needed.

**Figure 2-5. Schematic of Explore (Module B) Logic**

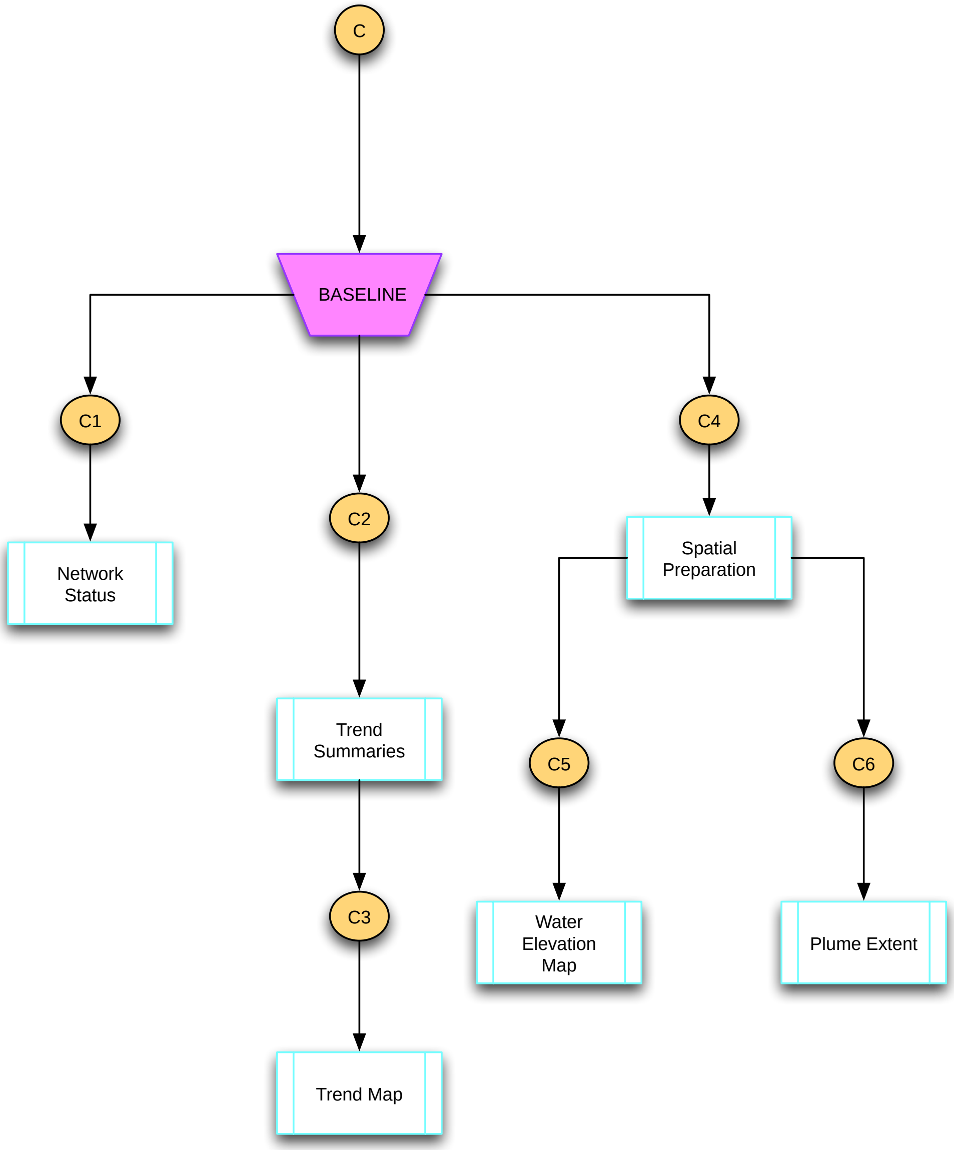



## Baseline Module

As indicated in the introduction, GTS achieves optimization via an *empirical definition of redundancy*: sampling events and/or wells are redundant if trends and maps initially built with data from those locations or events can be accurately reconstructed without subsequently using them (that is, utilizing only more critical wells and events). To this end, a key step prior to any GTS optimization is to create baseline trends and/or base-maps, using the original data set, in order to test the accuracy of reconstructions based on reduced-data subsets.

The Baseline module offers tools to construct such baseline trends and base-maps. Like data exploration in GTS, these tools can be employed in their own right if a user does not necessarily need an optimization, but instead merely wants documented estimates of temporal trends and/or maps of plume extent for each time slice. An overall schematic of the logic and features of Module C is given in **Figure 2-6**.

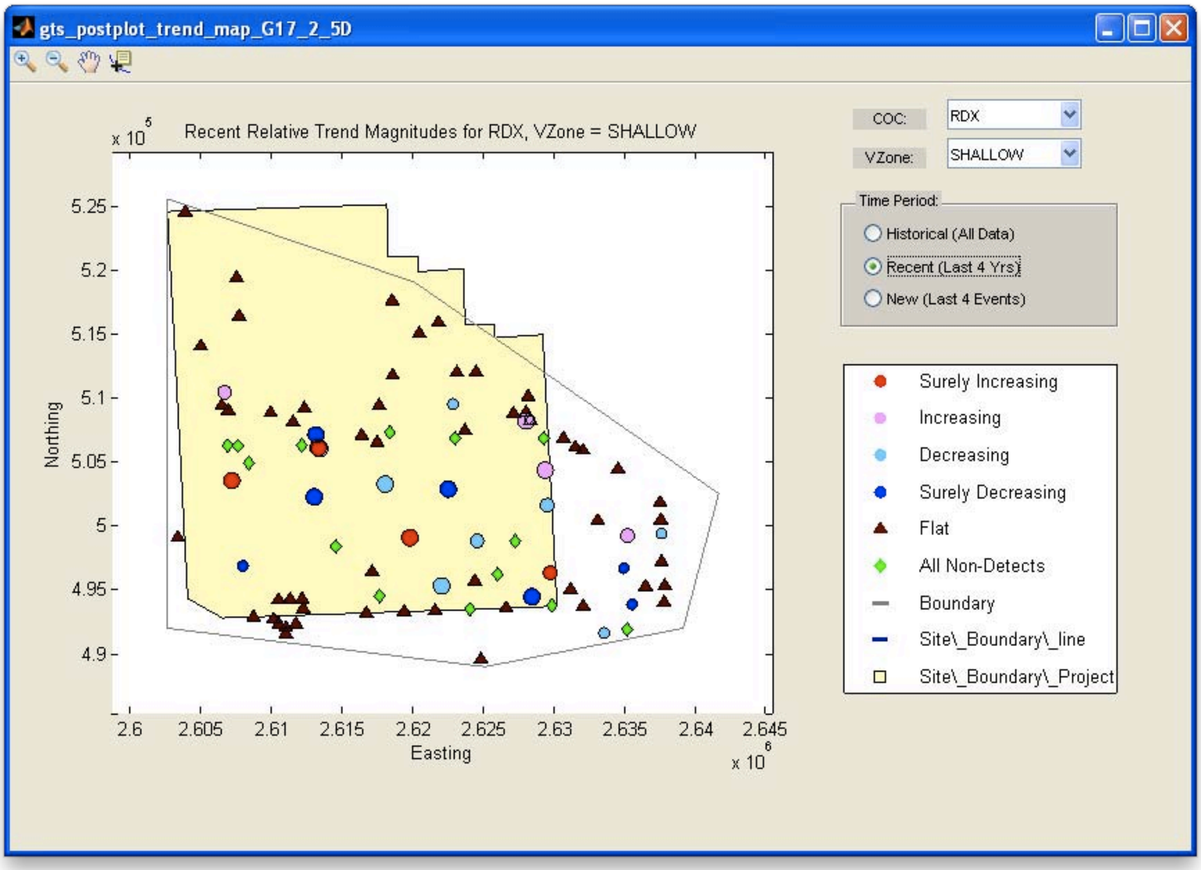
**Figure 2-6. Schematic of Baseline (Module C) Logic**




Trends are estimated in GTS via a type of local regression known as *locally-weighted quadratic regression* (LWQR), as it can fit complex and/or seasonal trends along with confidence bounds around those trends. LWQR constructs an estimate at any point (in time) $x$ as a weighted average of the sample measurements in a local neighborhood surrounding $x$. Local regression enjoys several optimal properties as a statistical technique [4], and several practical benefits: 1) it is inherently non-linear and thus capable of describing trends that are actively changing; 2) it estimates the average trend and thus provides a smooth estimate of how the mean concentration is changing over time; and 3) a by-product of the fitting process is a series of local trend *slopes* — these can be used to gauge rates and directions of change at particular points or periods of time.

This last benefit is exploited by GTS in constructing **trend maps**, which spatially represent trend 'movement' during a specific time period. These maps point to where different kinds of trends are occurring and how probable it is that the trends represent something 'real.' They can also be used to flag or confirm changes in plume extent over time, and to help identify areas of the site where additional sampling might be warranted (see **Figure 2-7**).

**Figure 2-7. Example Trend Map in GTS**




**Plume maps** (e.g., base-maps) are created in GTS using *quantile local regression* (QLR), a quasi-nonparametric fitting and spatial estimation procedure. QLR employs local regression instead of *kriging*, which unlike the latter: 1) does not require development of a spatial covariance model, but still accounts for the presence of spatial correlation; 2) as a smoother, does not assume that sample data values have been measured without error; and 3) does not require only one measurement per sampling location or per sampling event.

Instead of requiring an *a priori* spatial covariance model, the user decides on a degree of smoothness of the map through adjustment of a *bandwidth parameter*. In practice, the process is mostly automated, since GTS computes a default bandwidth for each map, which can be overridden when desired. As a *smoother* instead of an interpolator, local regression is akin to linear regression through a scatter cloud of points. The best-fitting line may not coincide with any specific point, yet it attempts to capture the overall trend. Similarly, a surface map fitted with local regression attempts to capture the best overall surface trend. The method explicitly assumes

each data point is measured with some degree of error. It also explicitly allows for multiple data points at any given location.

Standard forms of kriging require that there be only one data point per location to avoid colinearity in the kriging equations [5]. Given inconsistent sampling schedules across wells at most sites, choosing data from a given sampling event often does not include sampling information from all the wells of interest. But widening the ‘snapshot’ of time to include more wells typically leads to multiple data points at some locations, necessitating perhaps an averaging of these measurements before input to kriging, even though this action tends to reduce the observed variability of the data set and violate the assumption of identically distributed measurements.

Mapping in GTS does not apply local regression *directly* to the concentration data. Like other regression techniques, it assumes that residuals around the local trend or surface are approximately *normal* in distribution. But in practice, essentially every LTM network has: 1) significant fractions of non-detect measurements among one or more contaminants of concern (COCs), and 2) high levels of *skewness* in the (univariate) concentration distributions (i.e., significant non-normality). Neither of these data features is adeptly handled by standard spatial mapping techniques without the use of special data transformations.

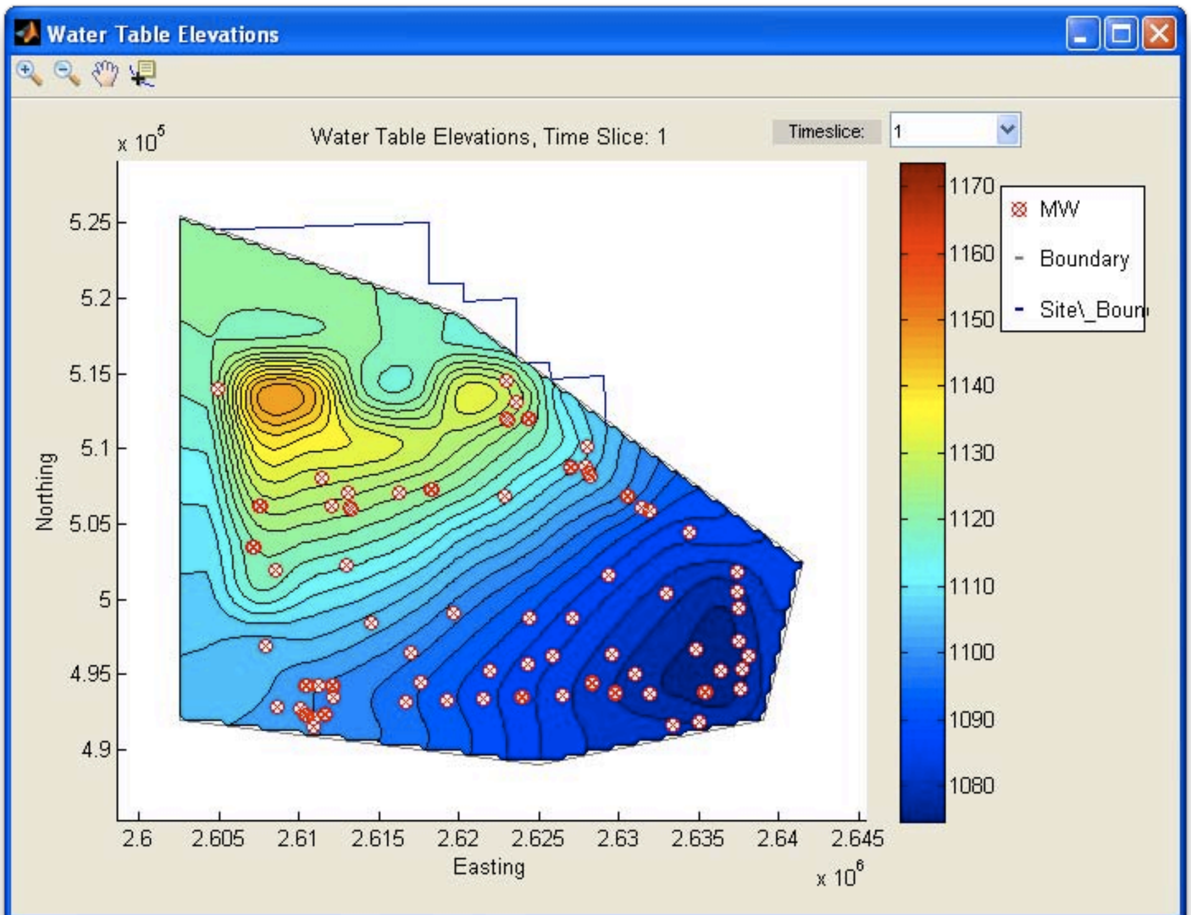
GTS accounts for these real-world difficulties by using QLR as a mapping engine. QLR first constructs an estimate of the overall observed (i.e., empirical) declustered concentration distribution (DCDF), based on recent concentration data from the site [‘declustered’ refers to adjusting the CDF for the preferential clustering of sampling locations in higher-level concentration areas] [5]. Then each concentration is converted to a value between 0 and 1 (i.e., the unit interval) using the DCDF, and further converted to values along the real line via a second *logit* transformation. These logit-transformed values are then fitted using local regression and the resulting estimates back-transformed utilizing the same two-step transformation process in reverse to get concentration-domain map estimates. The name *quantile* in QLR comes from the fact that the first step of the transformation changes each concentration into an equivalent quantile from the DCDF.

The advantages of QLR include: 1) non-detects can be handled without resorting to complicated imputation schemes; 2) the impact of extreme skewness is minimized since all estimation is done on the logit-transformed values and only afterwards back-transformed into concentration estimates; 3) plume detail and intensity can be reasonably captured since each logit-domain estimate is linked directly back to the observed concentration distribution at the site (i.e., DCDF); 4) a range of possible spatial models is fit to the observed data, with one model identified by GTS as the preliminary best choice; 5) the entire map building process is automated within the GTS software interface — except for choice of *spatial bandwidth* if the user decides to override the GTS-computed defaults — allowing an analyst to construct statistically-sophisticated maps without the need for expert consultation or set-up.

By design, GTS *does not* fully automate the process of fitting of either spatial or temporal models. Although standard statistical techniques such as *residual checking* are employed to help guide the fitting process, it is well known (see [4]) that strict reliance on ‘black-box’ modeling approaches can lead to poor-fitting models. In GTS, the user has the option to provide input at critical junctures in the model building exercise and override the GTS defaults.

In addition to the baseline trends, trend maps, and concentration base-maps, the Baseline module also provides the user with a visual and tabular overview of the baseline *network status*. The status report includes estimates of the empirically-derived baseline sampling frequency/interval associated with each well, as well as a graphical summary of which locations are 'critical' to the network, 'redundant,' or 'protected.' Connected with this last feature, users can designate selected wells as 'protected,' meaning that those particular locations are shielded from spatial optimization (i.e., always kept as critical wells and never classified as redundant). GTS also allows import of water level data and visualization of an estimated water table surface, along with how the water table changes across time slices (see **Figure 2-8**).

**Figure 2-8. Example Water Table Map**




## Optimize Module

Once baseline trends and base-maps are constructed, users can begin optimization. GTS offers separate temporal and spatial optimization functions, depending on the needs and data availability of different sites. **Temporal optimization** in GTS consists of two components: 1) *temporal variograms* applied to groups of wells, and 2) *iterative thinning* of individual wells. More than one temporal optimization method allows for flexible handling of the kinds of data available at different installations. Temporal variograms are most useful at sites with limited

sampling histories and less historical data. Iterative thinning, by contrast, reconstructs the entire trend at each well, a more difficult statistical task requiring larger amounts of data (generally at least 8 samples per well), but providing well-specific optimal sampling schedules and readily accounting for seasonal trends or fluctuations. **Figures 2-9** through **2-11** provide an overview of the logic and features of Module D.

**Figure 2-9. Schematic of Optimize (Module D) Logic — Temporal Redundancy**

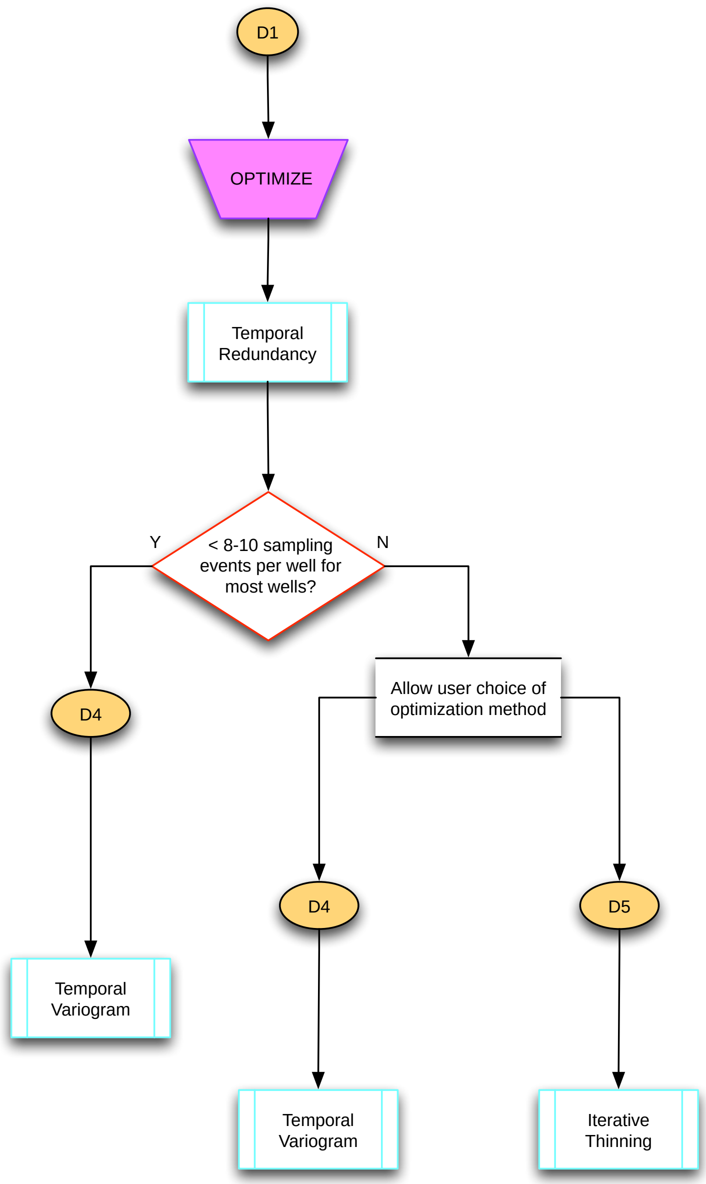


**Figure 2-10. Schematic of Optimize (Module D) Logic — Spatial Redundancy**

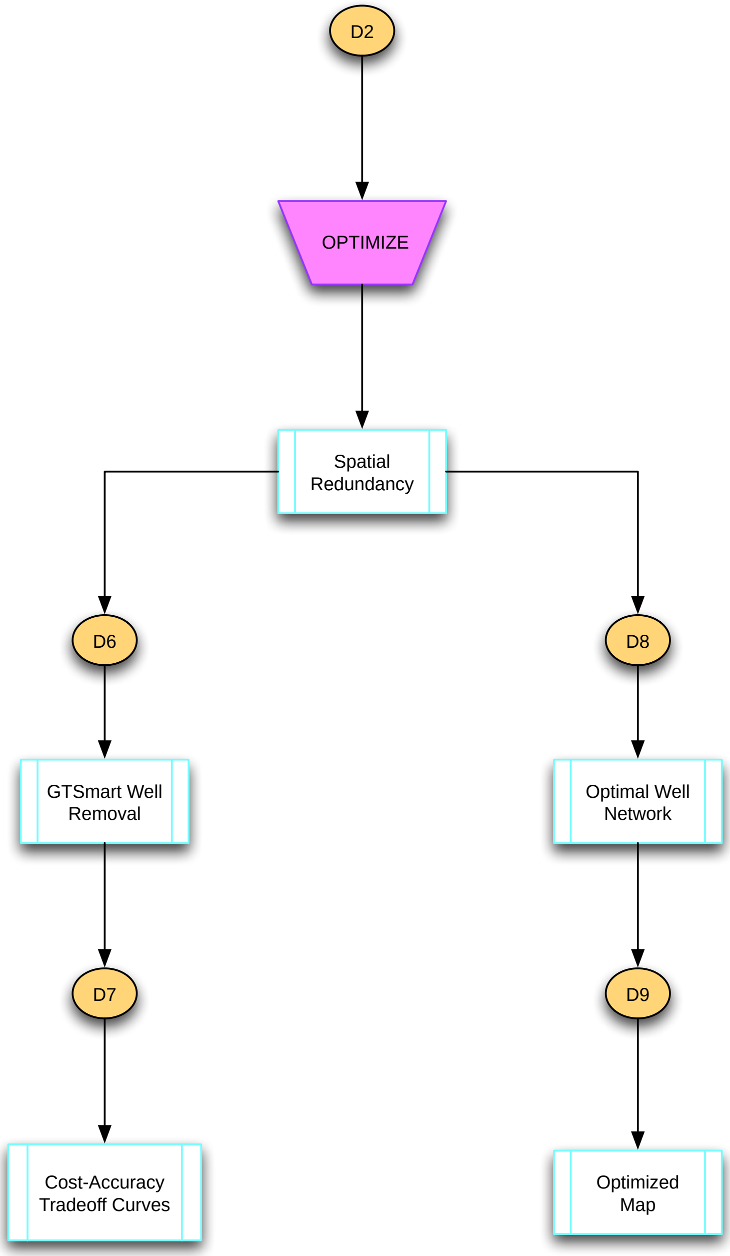
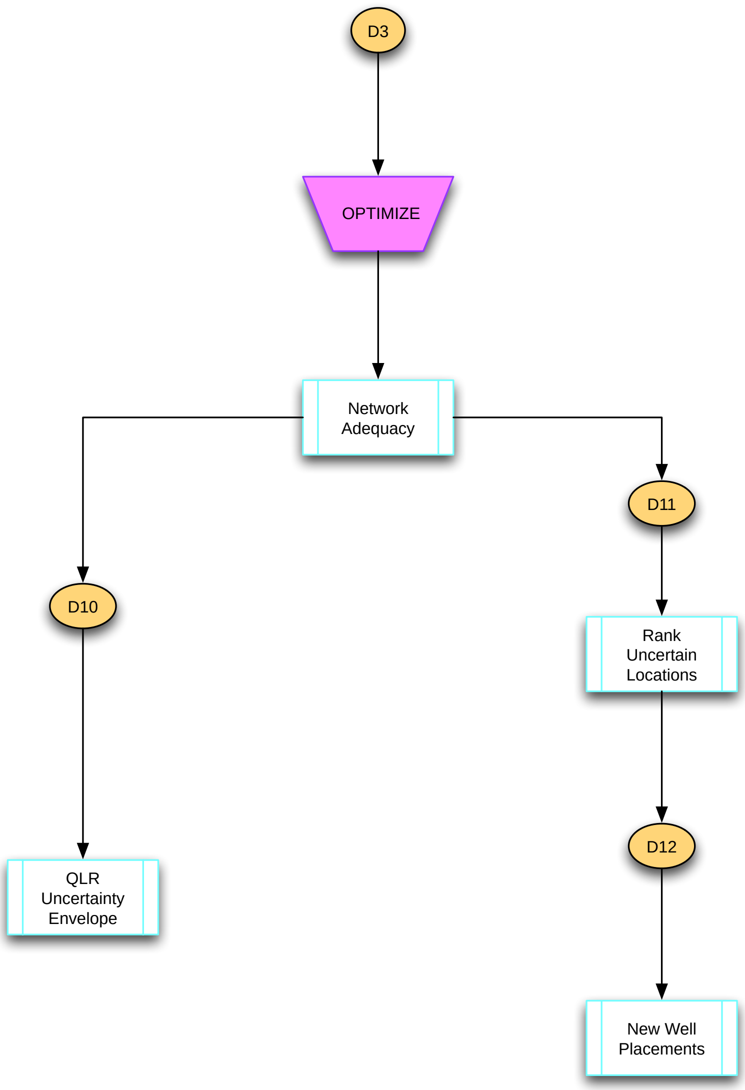


**Figure 2-11. Schematic of Optimize (Module D) Logic — Network Adequacy**

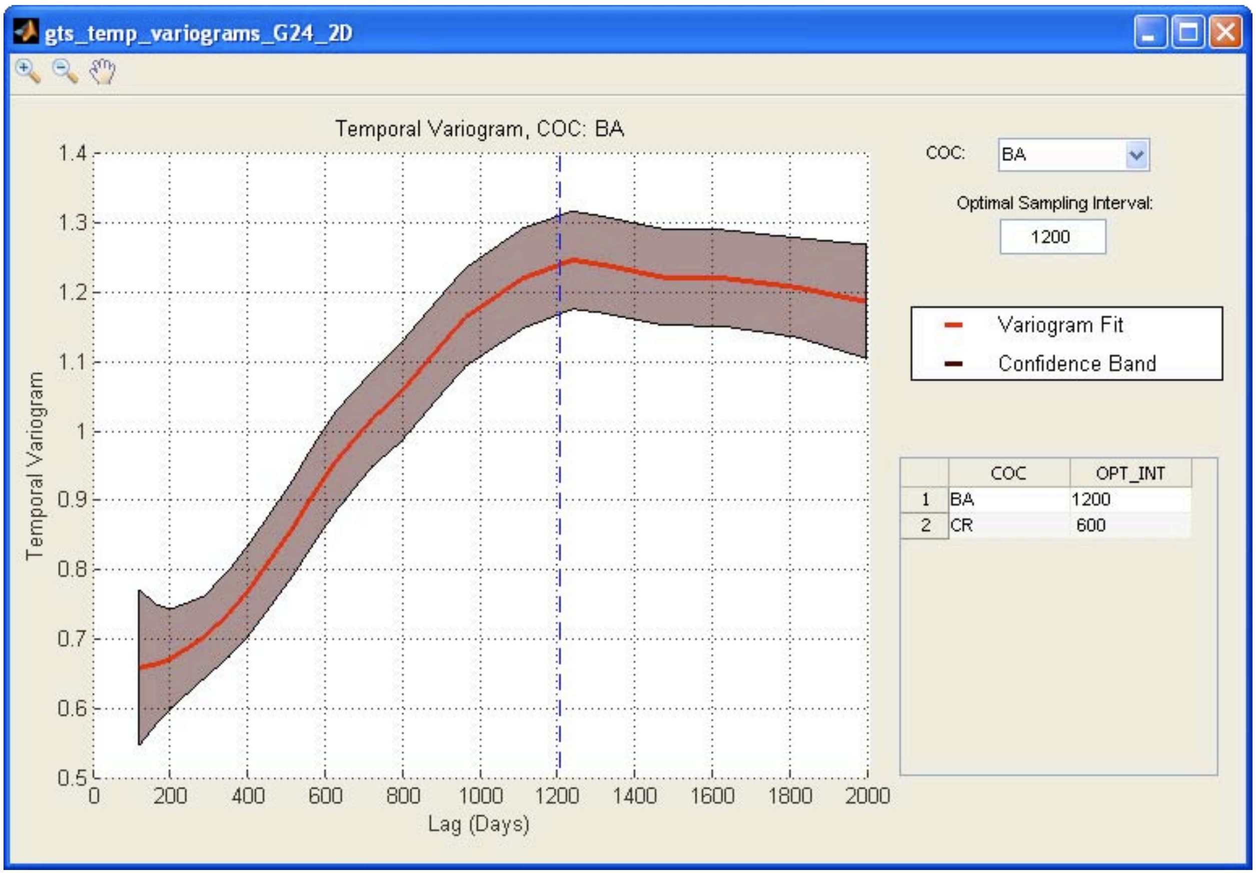



The **temporal variogram** optimizes sampling frequencies simultaneously over a *group* of well locations (see **Figure 2-12**). These locations might represent all wells at a given site, those connected with a particular regulatory unit, or that are part of a treatment system network. Whatever the grouping, the temporal variogram provides a single optimal sampling interval that can be applied to every well within the group. The temporal variogram itself is a *smoothed curve*, fit to a scatterplot of squared differences between all possible measurement pairs (*y*-values) versus the time lag between successive sampling events (*x*-values). The curve is estimated using locally-weighted quadratic regression (LWQR).

After GTS constructs the temporal variogram, the user is prompted to identify an approximate *range* in its structure. Because the variogram assesses the correlation between the

observed data and lag time between samples, positive temporal correlation is exhibited on the variogram by small values for small time lags and larger values for large time lags. Small values on a variogram indicate a high degree of correlation, while higher values represent a loss of correlation and greater statistical independence. The range is identified as the first lag at which the variogram begins to 'level off' or plateau. GTS sets the optimal sampling interval to this chosen *range* of the temporal variogram, if it exists. Sampling intervals smaller than the range are associated with correlated, and therefore somewhat redundant, sampling results.

**Figure 2-12. Example of Temporal Variogram in GTS**




**Iterative thinning** optimizes the sampling frequencies at *individual* wells. Because each location is analyzed separately, a different recommended sampling interval is generated for each well. GTS then combines these well-specific sampling intervals into a common operational sampling frequency for all the wells using the *median* optimal interval. Iterative thinning is based on a straightforward idea: 1) take the existing, historical data for a given well location and constituent, 2) determine the current average sampling interval, 3) fit a trend to these data along with statistical confidence bounds around the trend, 4) iteratively remove, at random, certain fractions of the original data, and 5) re-estimate the trend based on the reduced-data set to determine whether or not the trend still lies within the original confidence bounds. If too much of the new trend falls *outside* the confidence limits, stop removing data and compute a new, optimized sampling interval using the remaining data.

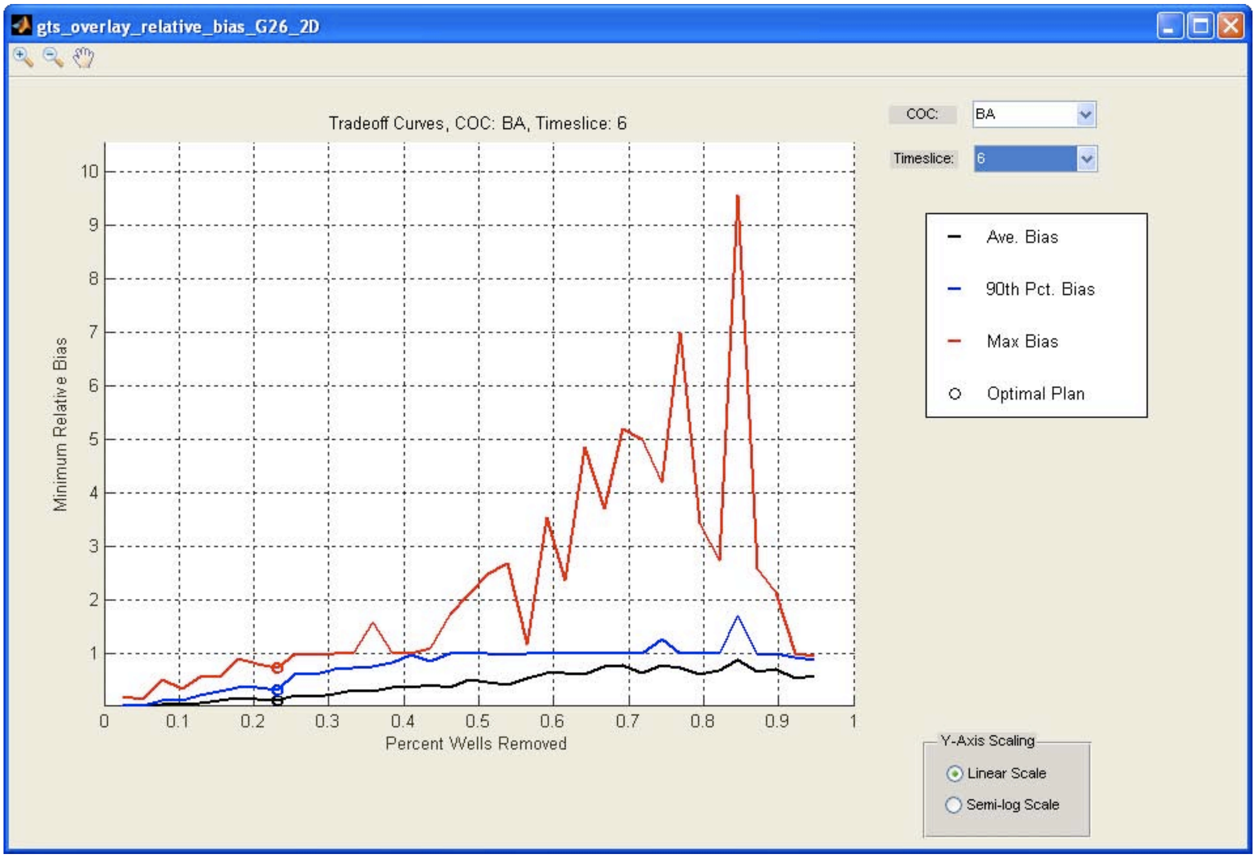
The other optimization function within GTS — **spatial optimization** — consists of the following steps: 1) *searching for statistical redundancy* via mathematical optimization; 2) *determining optimal network size* with the aid of cost-accuracy tradeoff curves; and 3) *assessing whether new wells should be added* and where (i.e., *network adequacy*).

To find spatial redundancy, GTS identifies optimal subsets of the existing monitoring network through *mathematical optimization*. This measures the degree of deterioration in GTS-estimated site maps by comparing site-maps made using a series of potentially 'optimal' *reduced-data* networks against their corresponding *base-maps*. GTS uses a quasi-genetic algorithm called *GTSmart* to search through alternate network configurations, where every alternate configuration temporarily removes a certain percentage of the wells. For each such configuration, a tentative site-map is constructed. Then the relative *residuals* (or relative differences) between the tentative concentration estimates on the site map and the corresponding base-map estimates are used to assess the degree of redundancy via three statistical measures: 1) *trimmed mean absolute bias*, 2) *upper 90th percentile absolute bias*, and 3) *maximum absolute bias*.

For each of these measures, bias is computed between the site-map and base-map estimates by taking the absolute value of the *logged ratio* between the site-map and base-map. The ratio of the two map estimates allows an estimate of the *relative* rather than *absolute* difference between the site-map and base-map; logging the ratio gives more statistical weight to mismatches between high areas of one map and corresponding low areas on the other (e.g., overestimating concentrations near boundaries of a plume). These necessarily positive-valued residuals are then plugged into standard formulas for computing the 95% trimmed mean, the upper $90^{th}$ percentile, and the maximum. Thus, three measures of bias are computed for each alternative site-map.

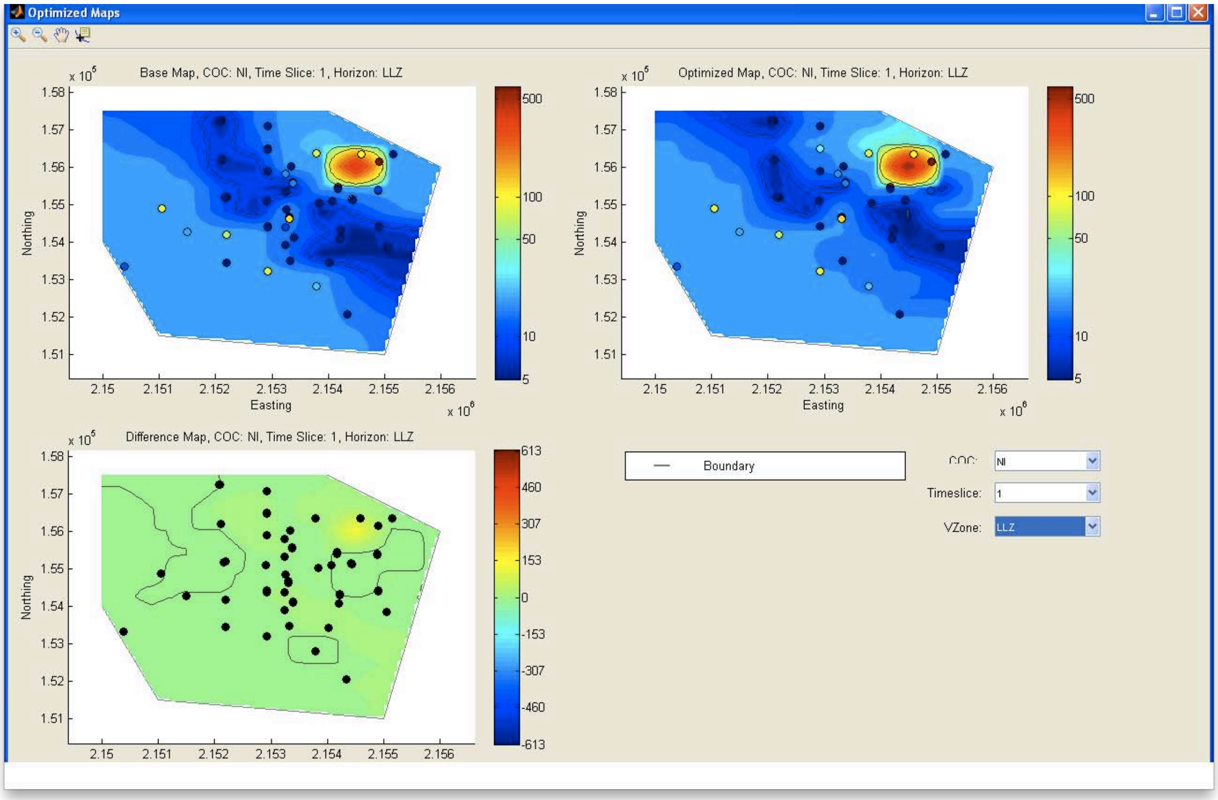
All three statistical measures are graphed against the degree of well removal, among the thousands of alternate configurations tested, to form **cost-accuracy tradeoff curves** (see **Figure 2-13**). Default, user-adjustable, limits on the acceptable levels of bias are also plotted. The tradeoff curves display the relationship between well removal and map bias, and identify at what point the bias measures exceed their limits. GTS designates a well configuration as *optimal* when it exhibits the largest degree of well removal among those configurations whose bias measures are still within the acceptable bias limits. In other words, an optimal well configuration balances reduction in cost (through the removal of wells) and consequent loss of map accuracy (as measured by bias). If many wells are statistically redundant, the tradeoff curves will indicate a significant cost reduction without substantial information loss. If few wells are redundant, the loss of accuracy will be large even when a small number of wells are removed.

**Figure 2-13. Example of Cost-Accuracy Tradeoff Curves in GTS**



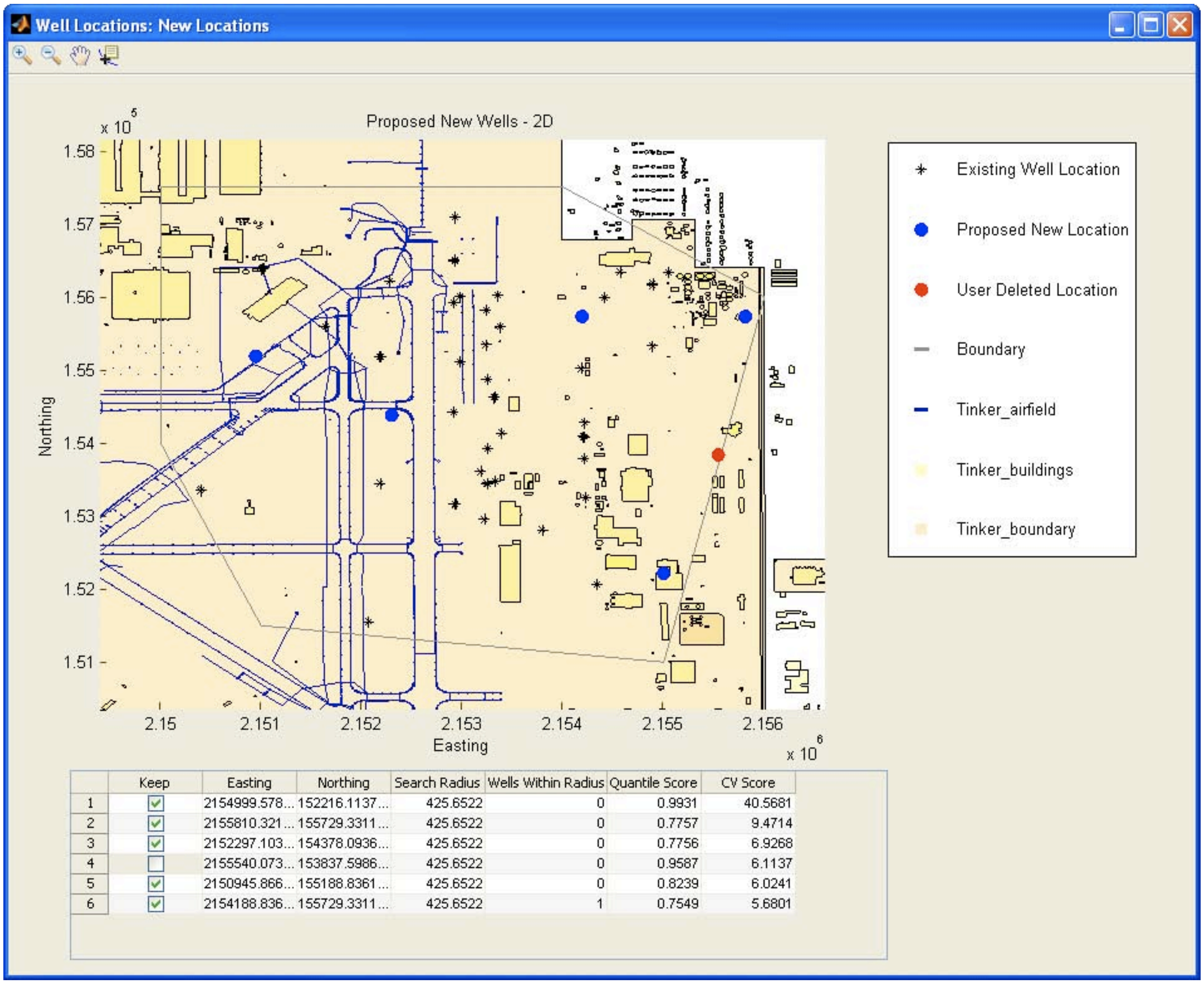

Once a point of optimality has been computed, GTS tags as redundant all wells that were not included in that configuration, for a given COC and period of sampling (i.e., time slice). The remaining wells are deemed critical to the network. The same process is repeated for other time slices and COCs and then combined automatically to determine a ranked list of critical and redundant wells at the site. The user is presented with a list of wells and their optimization status, along with a *post-plot* of the well network showing which locations are redundant and which are critical. GTS also displays side-by-side 'before and after' maps of the plume extent for each time slice and COC (and aquifer zone, if applicable), in order to document any differences due to the optimized network (see **Figure 2-14**).

**Figure 2-14. Example Baseline vs. Optimized Maps in GTS**




The last step of spatial optimization in GTS is the *network adequacy* analysis. This function determines whether any portions of the site warrant **new sampling locations**. To do this, GTS generates a *risk envelope* for each COC. The risk envelope is a map of estimated coefficients of variation (CV), a result of applying QLR at each pixel on the map to estimate both a (mean) concentration and its associated standard deviation for each time slice. The CV is simply this standard deviation divided by its associated (mean) concentration estimate (and then averaged across time slices), providing a unitless measure of uncertainty at each pixel. By combining and ranking these uncertainty values across COCs, GTS flags good candidate locations for the placement of new wells, subject to user override (see **Figure 2-15**).

**Figure 2-15. Example of Network Adequacy Post-Plot**



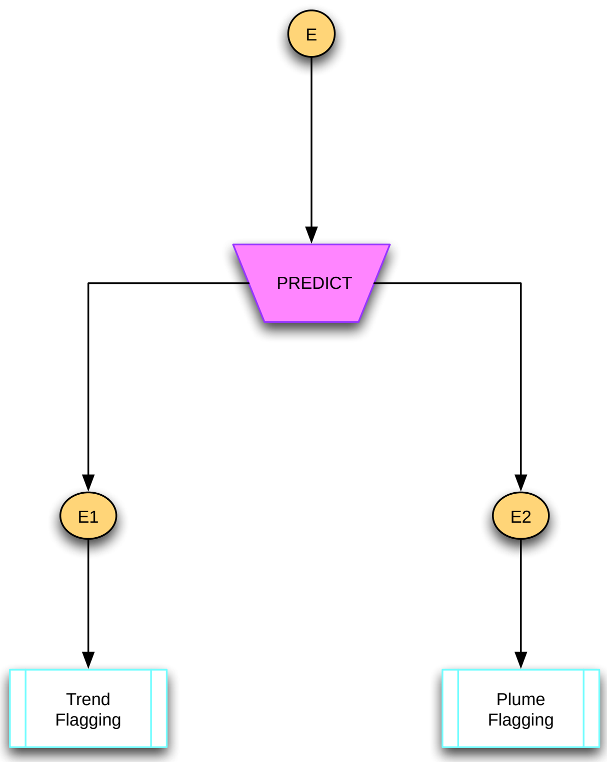

Once GTS optimization is completed, users can export tables of the results for use in the Excel-based GTS cost-comparison calculator. The calculator is designed to compute a realistic, site-specific return on investment (ROI) associated with a recommended optimized sampling program. It builds two sets of cost estimates: a baseline set representing the original (non-optimized) monitoring program and an optimized set using the GTS recommendations concerning sampling frequency and network size. It then computes the difference between these two sets of costs to determine the potential savings realized from optimization and the ROI.

To make the cost accounting as realistic as possible, the cost-comparison calculator allows site-specific entry of such factors as constituent groups (including relative sampling rates to account for parameters which are collected only sporadically or in select portions of the site); field sampling and analytical method costs; management, reporting, mobilization, and labor costs; costs for drilling any new wells; and costs associated with performing the optimization study. All of this information is combined with the GTS recommendations for which wells are critical or redundant, optimized sampling frequencies, and whether any new well locations are needed.

## Predict Module

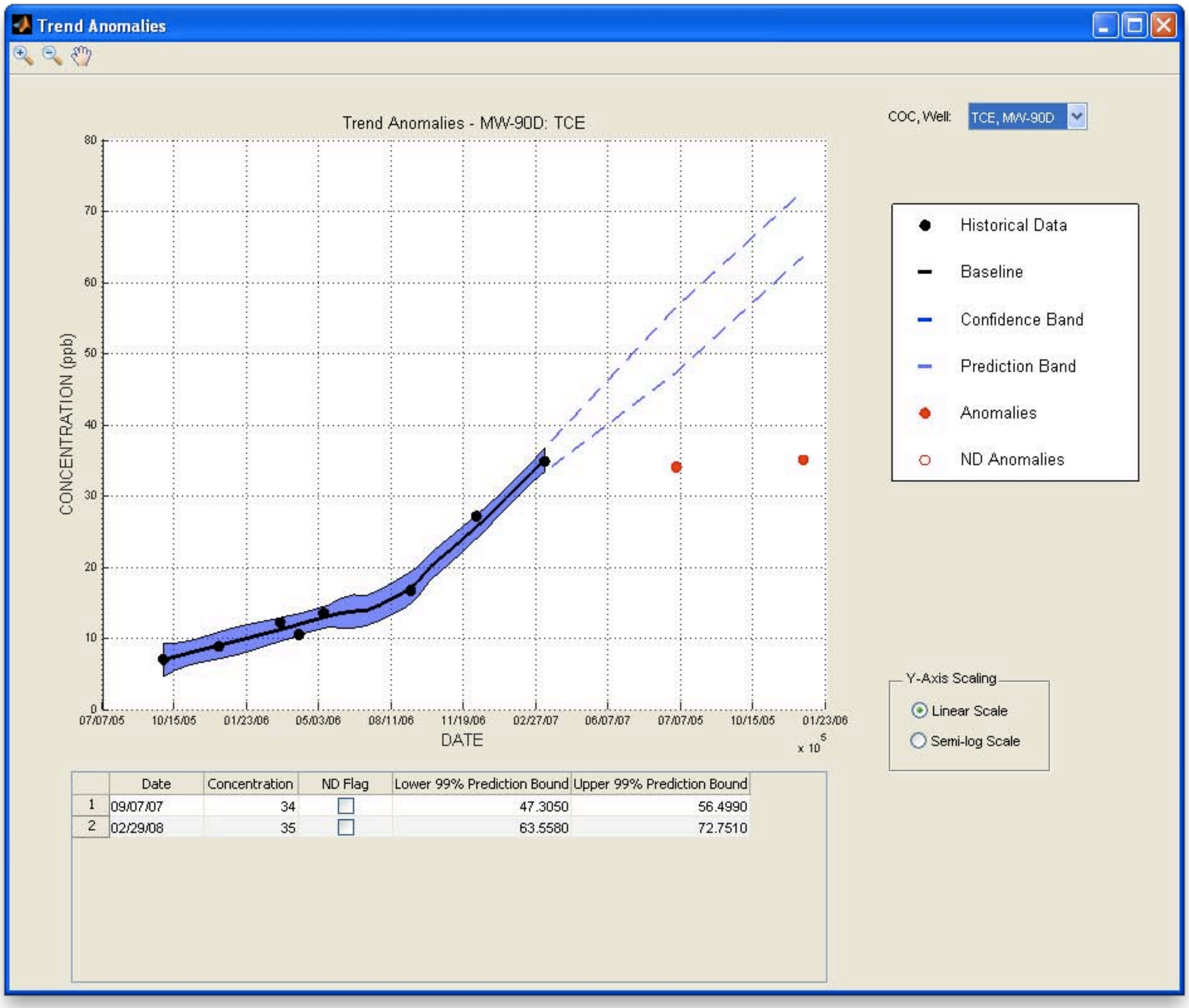
The last module allows users to import and compare new sampling data against previously estimated trends and maps. A schematic of the logic of the Predict module is given in **Figure 2-16**. The goal of these features is to enable identification of potential outliers, anomalous values, or 'early warning' changes in hydrogeologic conditions, plume intensity or extent. The two available options within GTS v1.0 include *trend flagging* and *plume flagging*. In the first, a *prediction band* around the baseline trend at each well is linearly extended into the future to the newly imported sampling events. If any new measurement falls outside the prediction band, that sampling event and the associated well are flagged (see **Figure 2-17**). Users can then investigate explanations for the apparent anomalies.

**Figure 2-16. Schematic of Predict (Module E) Logic**




The second option — plume flagging — has a similar purpose, but instead compares the new data against a *prediction envelope* constructed around the plume map. Data falling outside the envelope are flagged for additional follow-up. Of interest, unlike trend flagging, plume flagging can be utilized to check data sampled from new well locations that do not yet have a temporal history. It can also be utilized to periodically track abandoned wells, perhaps locations deemed redundant during optimization, to verify that the projected plume using the critical well network adequately reproduces concentration levels at locations no longer being regularly monitored.

**Figure 2-16. Example of Trend Flagging**




## 2.2 TECHNOLOGY DEVELOPMENT

Development of GTS as a decision-logic statistical algorithm began in 1998 under AFCEE sponsorship. The goal was to enable physical optimization of groundwater monitoring programs at a wide variety of Air Force facilities. Since that time, GTS has been applied and tested by MacStat Consulting and SAIC at over a dozen different DoD and Department of Energy (DoE) sites, including MMR, Massachusetts; Pease AFB, New Hampshire; Loring AFB, Maine; Edwards AFB, California; AF Plant 6, Georgia; Hanford, Washington; Tinker AFB, Oklahoma; and now through this project, AF Plant 44, Arizona; Former Army Nebraska Ordnance Plant (NOP); and the Fernald DoE site (Ohio). GTS has also been independently applied to several other sites by interested contractors and government analysts.

Each wave of application and GTS development added new features and improved characteristics of the algorithm. These improvements included:

- Switching from kriging in the initial GTS algorithm (prior to software development) to locally-weighted quadratic regression (LWQR) [6], and from multiple indicator local regression (MILR) in the revised algorithm (again prior to software translation) to the current quantile local regression (QLR) method in v1.0 of the GTS software
- Initially automating the search for redundancy using a steepest descent approach and now using a quasi-genetic algorithm (GTSmart)
- Using mathematical optimization and cost-accuracy tradeoff curves to determine optimality
- Enabling the fitting of complex and seasonal trends
- Adding trend mapping, and now trend and plume flagging, etc.

In past GTS testing, sites have included both single plumes and basewide studies; OUs, commingled plumes, and multiple sources; groundwater management areas (5 zones); multiple horizons; shallow water tables and confined aquifers; and well networks ranging in size from 30–1,200 wells. Hydrogeologic environments at which GTS has been tested have included homogenous sands and glacial outwash (MMR), compact glacial tills with overlying bedrock (Pease), carbonate rocks and fractured limestone (Loring), fractured crystalline bedrock overlain by weathered bedrock and alluvial layers (Edwards), unconsolidated alluvial deposits (Hanford), saprolite, weathered and transition zones (AF Plant 6), sandstone interbedded with siltstone and mudstone (Tinker), alluvial overbank deposits overlying sands and gravels (NOP), gravelly sand interbedded with mixtures of clay and sand (AF Plant 44), and areas that have been extensively excavated prior to monitoring (Fernald).

GTS analysis has been conducted on a wide range of COCs, including metals and inorganics, chlorinated solvents and other VOCs, indicator parameters, emerging contaminants, radiologic compounds, and explosives (e.g., RDX, TNT). Description of the GTS algorithm and case studies involving application of GTS have been published in scientific journals [3,6], conference proceedings [7-13], and in book and white paper excerpts [14, 15]. GTS was also featured as one of three primary and available groundwater LTMO methods in a series of workshops for regulators and consultants sponsored by EPA at various regional offices in 2005 and 2006.

Translation of the GTS algorithm into software began in 2004 to maximize the algorithm's flexibility and to reduce the degree of 'expert' analysis and consultation required. There was also a need to develop an easy-to-use software graphical user interface (GUI). The GTS beta software v0.6 and user guidance was freely distributed within the public domain by AFCEE via its RPO web site. The early version of the GUI allowed for simple, two-dimensional spatial analyses, along with temporal variograms and iterative thinning.

The ESTCP grant (ER-0714) awarded in this project has led to development of a stable, usable, and freely-accessible version of the software (GTS v1.0). The current version is built around a wizard-style interface and incorporates statistical and graphical engines (i.e., R and MatLab). It adds several new features: exploratory tools (including ranking of contaminants and analysis of vertical aquifer horizons), baseline trends and basemaps, improved spatial optimization (including both 2D and 2.5D analysis options), and both trend and plume flagging for tracking new data.

Up to this point, the Air Force and DoD have jointly invested over $1 million in GTS development and case study applications. The payoff in potential cost savings from application of GTS to Air Force and other sites is many times that amount in LTM reductions, especially as a freeware application.

## 2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

By way of overview, GTS attempts to balance the practical and scientific difficulties inherent in optimization schemes, namely, how to perform a scientifically defensible optimization analysis without requiring substantial involvement by statistical or mathematical experts. The software builds in several statistical and geostatistical analytical routines, all tailored to LTM optimization, yet woven into a user-interface designed to guide the user through a complex series of analyses. GTS is meant to be run by mid-level analysts with some — though not expert-level — statistical and geostatistical background.

### Benefits of GTS

The first and most important benefit of GTS is that it offers a more resource-effective long-term groundwater monitoring program. This benefit is realized in three primary ways:

1. By reducing sampling frequency and minimizing spatial redundancy in existing networks;
2. Through statistically-defensible addition of new well locations to better characterize contaminant plumes; and
3. Via trend mapping and trend flagging to better monitor changes over time in site conditions and to identify anomalies or unexpected sampling results.

A large number of DoD, DoE, and EPA sites could benefit from the techniques within GTS. Projected annualized and life-of-project cost savings from implementing a GTS-optimized program at a given site can be significant, in the range of 30%-60%. Return on investment for a GTS-optimized monitoring program is generally one to two years or less.

GTS is equally applicable to site-specific plumes, and unit-wide or base-wide studies involving multiple source areas, plumes, and monitoring conditions. This is because GTS does not require or utilize plume-specific configuration data, fate-and-transport models, or other hydrogeologic modeling information. Instead, it merely attempts to reconstruct maps and trends, based on the general extent of existing groundwater wells. GTS assumes that accurate reconstruction of these features will enable and assist continued regulatory, monitoring, and remedial decisions as needed, using the optimized network.

Operationally, GTS offers ‘stand-alone’ spatial and temporal optimization modules. Even at sites that are poorly characterized or have insufficiently large well networks to warrant a spatial analysis, a temporal optimization can still be conducted, including trend mapping and trend flagging. Past applications of GTS have demonstrated that most of the projected cost savings is realized through the temporal analysis.

Technically, GTS also offers several additional benefits. These include:

- Statistically-based, semi-objective LTM optimization, built to be run by non-experts. Most currently available tools either rely substantially upon qualitative review by expert hydrogeologists (in combination with statistical analysis) and/or offer less sophisticated and more heuristic statistical methods. GTS attempts to incorporate sophisticated statistical tools within a user interface negotiable and interpretable by mid-level analysts. GTS compliments and encourages professional judgment from stakeholders in negotiating an optimal monitoring plan.

- Innovative exploratory tools for assessing data characteristics, ranking COCs for optimization potential, and analyzing multiple aquifer horizons. These tools can also assist in the identification and development of anthropogenic or background data sets, such as are needed to set defensible concentration limits when delineating contaminated versus uncontaminated wells.

- Sophisticated built-in graphics for data visualization, including contour mapping, complex trends, postplots, and shape file annotation.

- Trend estimates derived from LWQR, allowing for fitting of complex and/or seasonal time series data. Other LTM optimization tools only offer fitting of *linear* trends, an assumption that does not match the reality of most LTM datasets. Most other methods do not provide a rigorous, non-subjective way to assess redundancy in sampling frequencies.

- Semi-nonparametric surface map estimates made using QLR, a smoothing technique not bound by the constraints of kriging [5]. By design, QLR can handle skewed datasets as well as significant proportions of non-detects, data features ubiquitous to LTM networks.

- Empirical, data-driven assessment of redundancy. GTS does not rely on the *kriging variance* — known to be a poor absolute measure of variability [16] — for judging spatial redundancy. Instead, a reduced-network is optimal if it can accurately reproduce the base-map.

- Automated redundancy searches, both during temporal and spatial optimization. The most complicated computational tasks only require a few clicks by the user within the GTS interface.

- Use of multiple cost-accuracy tradeoff curves to gauge points of optimality. Defensible bias measures of statistical accuracy allow for rigorous analysis of potential tradeoffs.

- A straightforward cost-comparison calculator that estimates cost savings to be realized from implementing the GTS-optimized monitoring program, using baseline cost data supplied by the user. The calculator also computes estimated return on investment (ROI) accrued from performing a GTS optimization [17].

- Summary reports of the results of GTS optimization; these include lists of optimal sampling intervals by well; recommended operational sampling intervals by site/area, well group, and/or aquifer horizon; lists of redundant and non-redundant well locations; and areas recommended for new wells.

### Limitations of GTS

Although extremely versatile and capable, v1.0 of GTS has certain limitations, some of which became apparent during this ESTCP demonstration:

- Effective spatial optimization in GTS requires a minimum of 15-20 wells and at least two sampling events per well; temporal optimization requires at least one well and 6-8 distinct sampling events per location.
- GTS requires a number of input fields in ASCII text format in order to create a sufficient analysis database. Some users may find the directions for importing data and creating or augmenting databases within GTS more complicated than need be.
- Quantile local regression (QLR), the GTS mapping engine, is by design a 'smoother' rather than an interpolator. That is, it may not replicate or 'honor' observed measurements when creating map estimates, unlike, for instance, kriging. To the extent these observations are precisely known or fixed, users may find QLR-based maps less appealing than interpolated maps.
- GTS does not offer sophisticated handling of radiochemical data, particularly measurements recorded with non-positive values (i.e., zeros or negatives). These data must first be converted to positive values, unless they represent non-detects with a known, positive detection or reporting limit.
- Optimized sampling intervals from temporal variograms in GTS often do not match the optimized sampling intervals from iterative thinning using the same data. Further improvements to the temporal variogram algorithm may be needed, especially to account for sites with spatial trends that are actively changing over time.
- Cost-accuracy tradeoff curves in GTS are not interactive. Although the bias limits can be adjusted by the user, the spatial optimization must be completely re-run each time those limits are changed, in order to see the impact of the revised limits and to generate a new optimal network.
- There is no way in GTS v1.0 to batch print graphics. Since a GTS analysis typically generates a large number of statistical graphics, users may be frustrated with the inability to document graphical results outside the application.
- The mathematical optimization algorithm in GTS is not a true genetic algorithm wherein portions of the binary string 'DNA' representing alternate network configurations are allowed to 'mate,' 'mutate,' and create 'offspring.' Instead, GTS does a 'smart search' through the space of potential network configurations, only selecting for testing those strings with interwell spacing comparable to the full network.
- GTS v1.0 does not track changes in contaminant or plume mass, nor does it allow users to specify contaminant mass as an optimization criterion.
- GTS may not give valid/accurate spatial results in subsurface environments that are highly fractured and discontinuous with poor hydraulic connection. Spatial mapping techniques in general (not just those in GTS) inherently assume that concentration patterns at known wells can be extended (e.g., interpolated, smoothed) to unsampled

locations. This may be problematic at sites with large contrasts in hydraulic conductivity (preferential pathways).

- There is no current method to correctly handle distinct well screens at different depths possessing the *same* location name and identical easting/northing coordinates. This limitation can occur with either direct push technology (DPT) samples that take multiple discrete measurements at different depths, but along the same borehole, or possibly with cluster wells that have multiple screens at distinct depths. As long as the name of each well screen or discrete sampling point/depth is unique, GTS will analyze the data appropriately. If identical names are used for such locations, however, regardless of depth, the user must adjust the naming convention outside the program.

**Other Technologies**

As of this writing, at least four other software technologies fairly similar in aim and/or scope to GTS have been or are being developed. These include the Three-Tiered Monitoring Strategy being developed by Parsons Engineering (www.parsons.com), Summit Tools developed by Summit Envirosolutions (www.sampleoptimizer.com), MAROS developed by GSI Environmental (www.gsi-net.com/software/free-software/maros.html), and the Identify Sampling Redundancy feature of VSP v6.0 developed by Battelle (http://vsp.pnl.gov/index.stm).

The **Three-Tiered Monitoring Strategy** has not yet been released as stand-alone software, but is currently under development. Until now, it has been a proprietary algorithm used on a consulting basis. Substantial emphasis is placed upon expert qualitative review by a consulting hydrogeologist. The Three-Tiered approach does not use mathematical optimization to identify redundancy. The temporal analysis does only linear fitting of trends and uses a rule-based, rather than empirical, strategy to derive optimal sampling frequencies.

**Summit Tools** was developed under ESTCP grant ER-0629 and released in 2009. The ESTCP version is a proprietary software system that is free for use by government and DoD employees; commercial users must buy an annual license. All users must purchase upgrades if desired. It relies in part on kriging for spatial mapping, but also incorporates other spatial modeling techniques, as well as automated redundancy searches based on efficient genetic algorithms. Summit Tools utilizes an automated ‘semi-black box’ approach to spatial modeling (users can alter variogram and/or kriging parameters), with its attendant risks, in order to simplify user input. Sampling frequency optimization is handled via a joint spatio-temporal redundancy search. This requires highly regular baseline sampling intervals to be effective. Summit Tools also includes a Data Tracker module designed to identify potential anomalies/outliers in new data, based on linear or exponential-decay projections of baseline trends.

**MAROS** was also developed under the auspices of AFCEE and is freely available. As an optimization software product, MAROS is the most mature of the competing technologies, but lacks many of the advanced statistical features included within either GTS or Summit Tools. It fits linear trends and offers a heuristic, rule-based approach for determining optimal sampling frequencies. MAROS does not perform spatial mapping, per se, but relies on Delauney triangulation and nearest neighbor analysis to assess spatial redundancy. Users desiring detailed site maps must employ third-party mapping software. Only one measurement per sampling event

and location is allowed when conducting spatial evaluations. A new version of MAROS is currently under development and promises to add significant new capabilities.

**VSP** recently released a new geostatistically-based set of optimization features for conducting spatial optimization of well locations and temporal optimization of sampling frequencies. These features closely mimic earlier versions of GTS. Documentation of these capabilities is contained in the VSP v6.0 User's Guide (June 2010).

Although other optimization approaches exist (for instance [18-20]), they depend in large measure on coordinated use of numerical groundwater simulation models (e.g., fate and transport). Some utilize Kalman filters and/or simulated annealing to update the models and predict where in the network uncertainty might most be reduced. None of these methods has apparently been translated into stand-alone, public domain software. Furthermore, numerical groundwater models are not available at a majority of potential sites where GTS might be utilized.

To roughly compare the features offered by GTS, MAROS, the Three-Tiered approach, Summit Tools, and VSP, the following 'measles chart' in **Figure 2-17** gives a comparative overview.

**Figure 2-17. LTMO Software Feature Comparison Chart**

| Feature/Capability | GTS | MAROS | Summit Tools | 3-Tiered | VSP |
|---|---|---|---|---|---|
| Built-in Database | ● | ● | ● | ● | ● |
| Data filtering, manipulation | ● | | | ● | ● |
| Rich visualization, statistical graphics | ● | | ● | | ● |
| Data checking, outlier search | ● | | | | |
| Freeware | ● | ● | | ● | ● |
| Publicly released | ● | ● | ● | | ● |
| Print/Save reports | ● | ● | ● | ● | ● |
| Exploratory data tools | ● | ● | | ● | ● |
| COC/analyte analysis | ● | ● | | ● | ● |
| Multiple horizon analysis | ● | | | | |
| Linear trends | ● | ● | | ● | ● |
| Complex, non-linear trends | ● | | | | ● |
| Trend analysis | ● | ● | | ● | ● |

| | | | | | |
|---|---|---|---|---|---|
| Trend maps | ● | ● | | | |
| Mapping engine | | | | | |
| Quantile local regression | ● | | | | |
| Kriging/Quantile kriging | | | ● | | ● |
| Delauney triangulation | | ● | | | |
| Water table mapping | ● | | | | |
| Mass flux/moment analysis | | ● | ● | | |
| Temporal optimization | | | | | |
| Temporal variograms | ● | | | | ● |
| Iterative thinning | ● | | | | ● |
| Cost Effective Sampling (CES) | | ● | | | |
| Spatio-temporal optimization | | | ● | | |
| Spatial optimization | | | | | |
| Mathematical optimization | ● | | ● | | |
| Optimize by multiple site objectives | | | ● | | |
| Steepest Descent (i.e., sequential, well-by-well) | | ● | | | ● |
| GTSmart (quasi-genetic) search | ● | | | | |
| Genetic algorithm search | | | ● | | |
| Network adequacy analysis | ● | ● | | | |
| Cost-comparison calculator | ● | | | | ● |
| Spatio-temporal optimization | | | ● | | |
| Built-in qualitative analysis | | | | ● | |
| Data Tracking | | | | | |
| Trend flagging/data tracker | ● | | ● | | |
| Plume flagging | ● | | | | |

# 3.0 PERFORMANCE OBJECTIVES

This section provides a summary of the performance objectives stated in the Technical Demonstration Plan for evaluating GTS in this project, including a conclusion as to whether or not each performance objective was met. **Table 3-1** summarizes these performance objectives. To avoid repetition, a detailed discussion of each performance objective is deferred until **Section 6.0** that explains the criterion, how it was assessed, and the basis for the assessment.

**Table 3-1. Performance Objectives**

| Performance Objective | Data Requirements | Success Criteria | Criteria Met? |
|---|---|---|---|
| **Qualitative Performance Objectives** | | | |
| Ease of use, software (primary) | Feedback from independent site testers operating the software | Users find GTS easy to use as indicated by user feedback and by general lack of error or system crashes in installation and use | YES |
| Ease of use, user manual (primary) | Feedback from independent site testers using the manual | Users find GTS manual easy to use and understand | PARTIALLY |
| Graphical output requires limited explanation (secondary) | Feedback from independent site testers operating the software and interpreting results | Users find GTS graphical outputs require limited explanation | YES |
| Software reliability (primary) | Feedback from software beta testers | By end of project, GTS does not have any significant bugs | YES |
| Release GTS as fully-functional, stand-alone freeware (primary) | Complete/upgrade GTS interface and computational engine using open-source and license-free runtime coding tools | GTS is free-to-use, stand-alone desktop application with a single (.exe) installer | YES*<br>*Separate cost-comparison calculator is currently an Excel spreadsheet |
| Accessible to non-experts (primary) | Design user interface so that GTS can be run and interpreted by those without expert statistical training | GTS can be successfully performed and interpreted by mid-level analysts | YES |
| Robustness (primary) | GTS analyses from a cross-section of site conditions and COCs | Can be applied across sites with a variety of constituents of concern (COCs), hydrogeologic terranes, remedial solutions, etc. | YES |

| | | | |
|---|---|---|---|
| Water level-aided mapping (secondary) | Develop spatial mapping option that utilizes both concentrations and water head-level data | GTS can create maps based on either concentrations or a combination of concentrations and water-level data | NO/PARTIALLY |
| **Quantitative Performance Objectives** | | | |
| Ease of use (primary) | Log of number and type of operational difficulties encountered by independent site analysts | GTS users encounter few operational difficulties | PARTIALLY |
| Reproducibility of temporal optimization (primary) | Quantitative comparison of temporal optimization results between GTS Design Team and independent site analysts | Expert and new users arrive at similar reductions in monitoring frequency using same site data and information | YES |
| Reproducibility of spatial optimization (primary) | Quantitative comparison of spatial optimization results between GTS Design Team and independent site analysts | Expert and new users arrive at similar optimized network configurations (i.e., placement of wells) using same site data and information | YES |
| Predictability (secondary) | Quantitative assessment of reserved validation data from each demonstration site | GTS Predict module successfully projects trend and plume estimates to encompass >90% of near future measurements | PARTIALLY |
| Optimization effectiveness (primary) | Numerical measures of degree of temporal and spatial redundancy identified at each demonstration site, along with associated cost savings | GTS is able to identify significant redundancy in larger groundwater monitoring networks and can generate optimized sampling programs | YES |
| Accuracy (primary) | Numerical comparisons between GTS base-maps/trends and site concentration data | There is a low degree of statistical difference between original site data and GTS-constructed base-maps and trends | YES/PARTIALLY |
| Versatility (primary) | GTS analyses for larger sites with more than 200 well locations | Revised software is able to perform optimization at sites with >200 wells | YES |
| Return on investment (ROI) (secondary) | Cost-benefit analyses from demonstration sites | Projected return on investment is ≤ 3 years at each site | YES |

# 4.0 DEMONSTRATION SITE DESCRIPTIONS

Two DoD and one DoE demonstration sites were selected. Potential sites were initially screened to meet criteria for data history and monitoring network size:

- Data history — full temporal optimization in GTS requires a minimum of eight distinct monitoring events for most groundwater wells
- Network size — spatial optimization in GTS requires at least 15-20 distinct well locations; to achieve the performance objective for versatility (see **Table 3-1**), some sites with more than 200 well locations were required

In selecting the sites, the project team also strove for variety in terms of hydrogeology, nature and extent of contamination, size of the monitoring program, and amount of data history available. There was also a preference, if possible, to select each site from a different federal agency. Furthermore, the project team looked for willingness on the part of the site team to participate in the effort and consider implementation of results. **Table 4-1** provides a summary of the demonstration sites.

**Table 4-1. Characteristics of Demonstration Sites**

| | **Air Force Plant 44** | **Fernald Site** | **Former Nebraska Ordnance Plant (NOP)** |
|---|---|---|---|
| **Agency** | Air Force | Dept of Energy | Army |
| **Location** | Tucson, AZ | Ross, OH | Mead, NE |
| **Geographic Location** | West (arid) | Mideast (Ohio valley) | Midwest (plains) |
| **Remediation System** | Pump & Treat with 25 extraction wells | Pump & Treat after extensive excavation of contaminated soils | Pump & Treat with 10 extraction wells |
| **Primary COCs** | TCE, Chromium, 1,4-Dioxane, 1,1-DCE | Uranium | TCE and RDX |
| **Aquifers Evaluated** | SGZ, UZUU, UZLU, LZ | Single aquifer | SHALLOW, MEDIUM, and DEEP aquifers |
| **Sampling Frequency** | Quarterly (most wells) | Quarterly (most wells) | Semi-annual, but varies by well |
| **Monitoring Network** | 208 (206 at risk) | 467 wells and DPT locations (376 active) | 250 (177 at risk) |

Figures regarding site location, stratigraphy, and contaminant plumes that are presented in the following sections for each of the three demonstration sites are taken from site reports provided to the ESTCP project team.

## 4.1 SITE LOCATION AND HISTORY

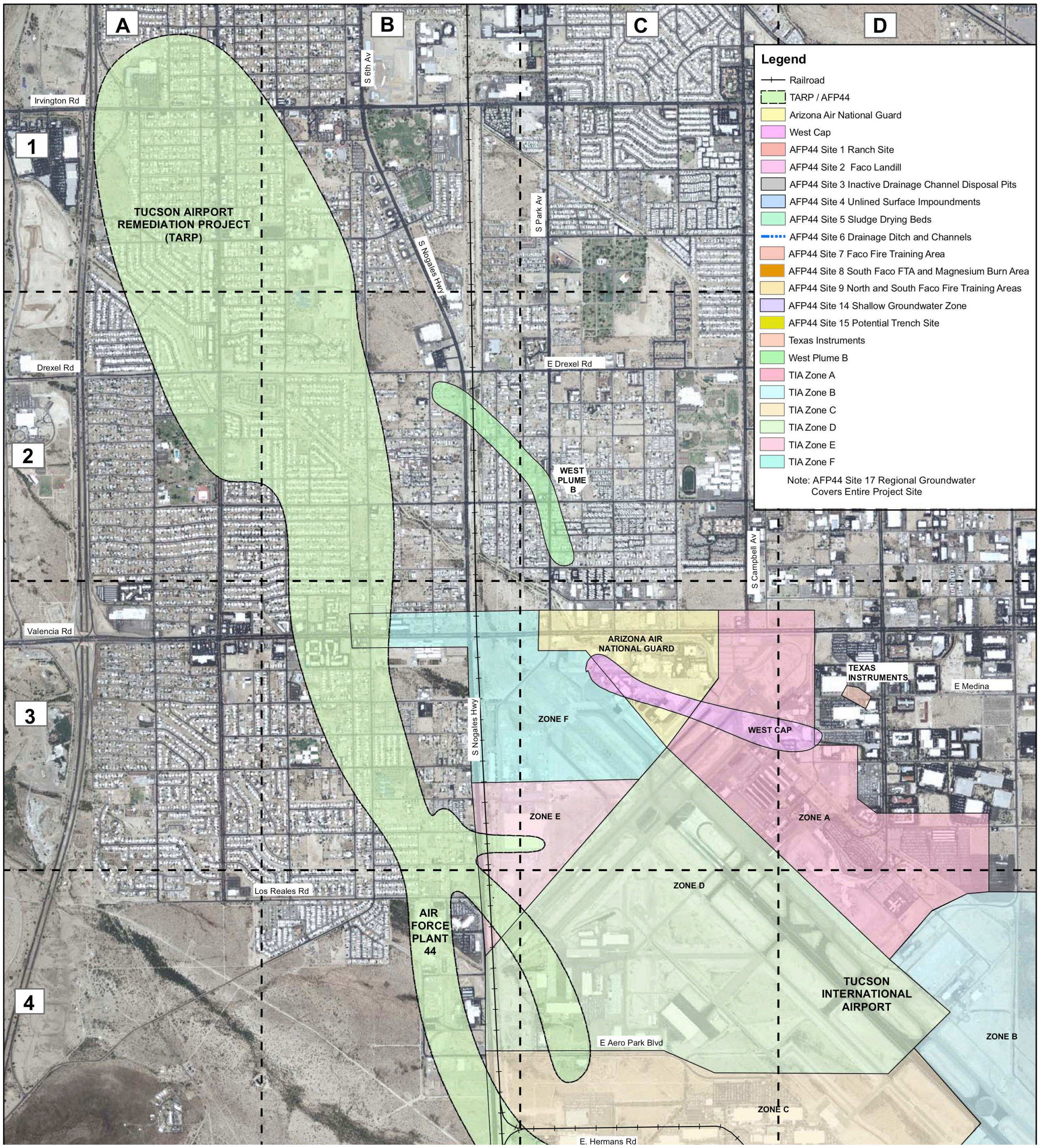
### Air Force Plant 44, Tucson, AZ

AFP44 is located in the northern portion of the Tucson Basin within the Sonoran Desert section of the basin and range physiographic province in southern Arizona (see **Figure 4-1**). The basin is bounded on the west and south by the Sierrita, Black, and Tucson Mountains, on the south and southeast by the Santa Rita Mountains, and on the east and north by the Empire, Rincon, Tanque Verde, Santa Catalina, and Tortolita Mountains. Elevations range from 2,500 feet above sea level in the center of the basin to 9,400 feet above sea level in the Santa Rita Mountains.

Weapons manufacturing at AFP44 began in the 1950s and continues today at the government-owned, contractor-operated facility. From the 1950s through the mid 1970s, hazardous materials were stored, handled, and disposed in a manner consistent with widely accepted industry practices of the time. Releases to the environment occurred involving primarily chromium and chlorinated solvents, including TCE, 1,1,1-TCA, and 1,4-Dioxane, a solvent stabilizer. The primary known release sources included sludge drying beds, unlined lagoons, degreasers, and uncontrolled landfills. Chlorinated solvents associated with AFP44 are present in off-site groundwater to the northwest, commingled with the same compounds released from other nearby sites.

Groundwater impacts were discovered in the early 1980s at AFP44 and were investigated by the USAF to define the extent and magnitude of the contamination. An extensive drilling and sampling program, followed by a human health risk assessment, led to the identification of several sites where contaminant concentrations were sufficiently elevated to warrant remediation.

**Figure 4-1. Air Force Plant 44, Tucson, Arizona**




Remedial actions at AFP44 were initiated in 1986 with the implementation of a site-wide groundwater extraction and injection system referred to as the “Groundwater Reclamation System.” The groundwater treatment plant (GWTP), which treats groundwater collected by the system, was designed to remove both chromium and chlorinated solvents from extracted groundwater at rates up to 5,000 gallons per minute (gpm). Chromium treatment was

discontinued at the GWTP in 1994 when treatment switched to a well-head system that targeted only those wells where chromium exceeded the maximum contaminant level (MCL). The Groundwater Reclamation System continues to treat chlorinated solvents in groundwater, with some modifications implemented in the 1990s to maximize contaminant mass removal. After 22 years of operation of the groundwater treatment system, as well as successful operation of five soil remediation systems, the chlorinated solvent plume in the regional groundwater has been significantly reduced.

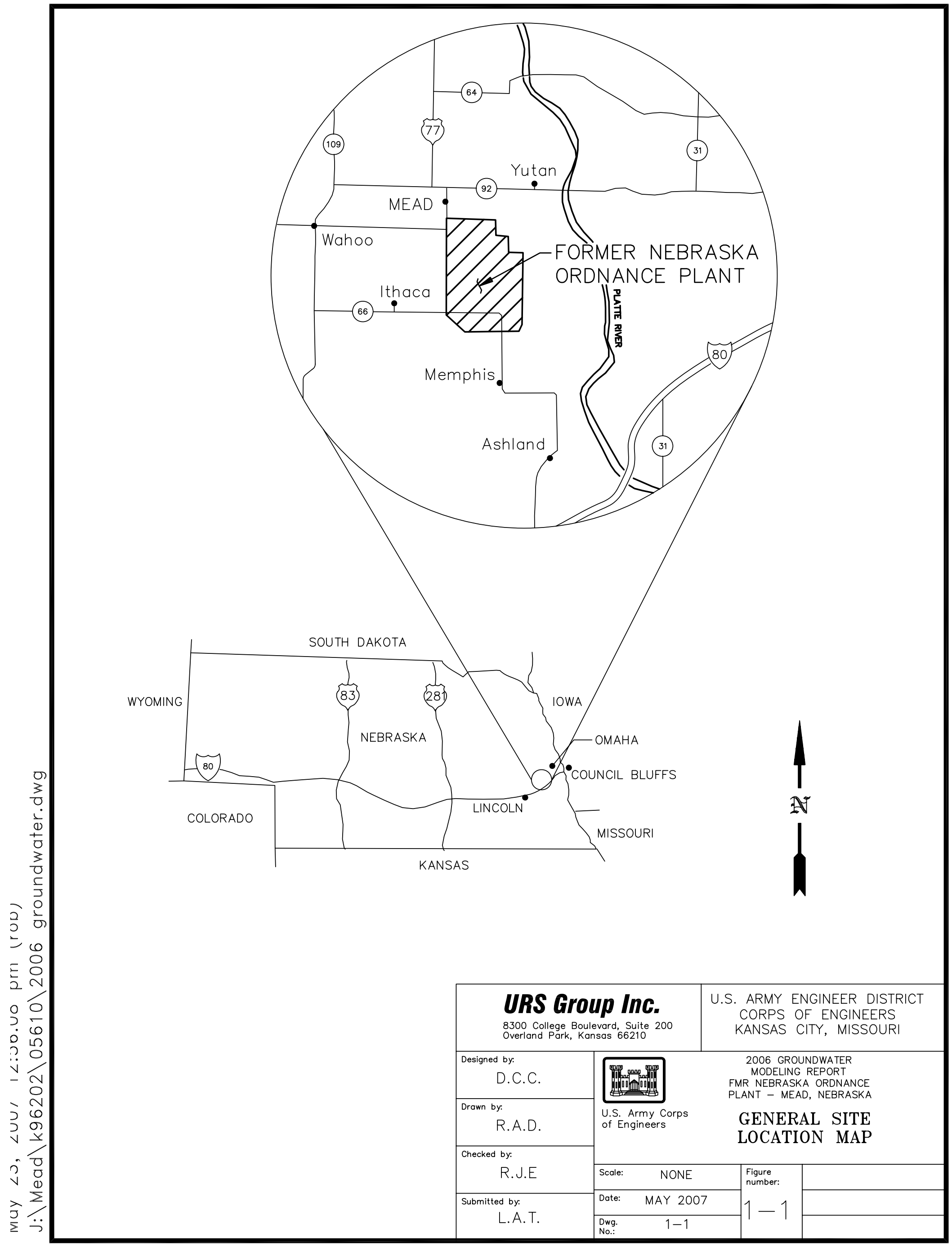
Sampling was conducted for 1,4-Dioxane at AFP44 in the early 1990s; however, no detections were noted in analytical results. An improved, more accurate method of sampling (EPA Method 8270, Modified) was developed to analyze 1,4-Dioxane at a lower detection limit. The new method allows 1,4-Dioxane to be detected at 1-2 ppb detection levels as opposed to the older detection level of 100 ppb.

**Former Nebraska Ordnance Plant (NOP), Mead, NE**

The former NOP occupies approximately 17,250 acres located 0.5 miles south of the town Mead, Saunders County, Nebraska (**Figure 4-2**). The Site is nearly flat, with a few gentle slopes. Surface water drainage in the eastern portion of the site is generally to the southeast. In the western portion of the site, surface water drains to the southeast, via Silver Creek. During World War II and the Korean Conflict, bombs, shells, and rockets were assembled at the site. The site includes four load lines (LL1 is furthest west and LL4 is furthest east), where bombs, shells, and rockets were assembled; the Burning/Proving Grounds; a Bomb Booster Assembly Area; Administrative Area; an Air Force Ballistic Missile Division Technical Area; and an Atlas Missile Area. The ammunition load lines are located slightly over two miles south-southeast of Mead.

According to previous reports, wastewater with explosives from both the load line plant operations and a laundry was discharged into a series of sumps, ditches, and underground pipes. TCE was released from various sources including the Atlas missile site. The site was placed on the U.S. Environmental Protection Agency (EPA) National Priorities List (NPL) of Superfund sites in August 1990 because contamination was identified in the groundwater and the soils at the site, and the release of contamination from this site is considered to be a potential threat to public health, welfare, and the environment.

**Figure 4-2. Former Nebraska Ordnance Plant (NOP), Mead, NE**



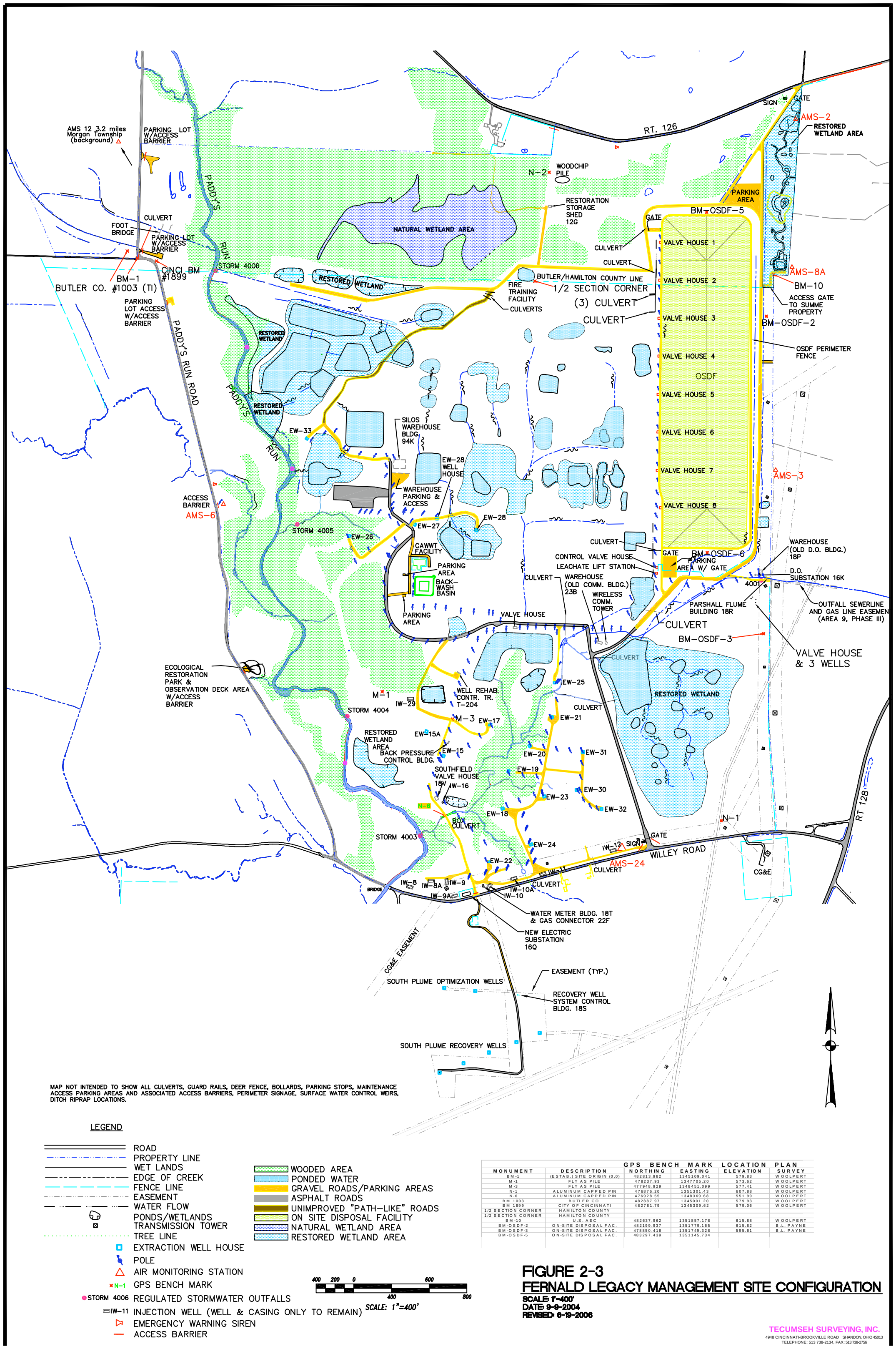

## Fernald DoE Site, Ross, OH

The Fernald Site is located near Ross, Ohio about 18 miles northwest of Cincinnati (**Figure 4-3**). It occupies 1,050 acres of land, 136 of which were covered by buildings when DoE had

active operations there. Its mission was to produce uranium metal for use as fuel in DoE nuclear reactors. The Fernald Site operated in this capacity for nearly 40 years, from 1952-1989, before being shut down. Altogether, 462 million pounds of high-purity uranium metal were produced, along with 2.5 pounds of waste per pound of refined uranium. Thus, approximately one billion pounds of waste materials were stored at the facility during its operational life.

After production activities at the site ceased in 1989, the 1990s were dedicated to site remediation activities, including the demolition and removal of buildings, the excavation of contaminated soils, and the construction of an on-site disposal facility as a repository for demolition debris and contaminated soils. In addition, historical site activities had resulted in groundwater contamination that migrated off-site, with uranium the primary contaminant of concern. Active remediation (pump and treat) was used to contain and treat contaminated groundwater. In the early 2000s, primary remediation activities at the site were completed, leaving only active groundwater remediation taking place, along with its associated groundwater monitoring network.

**Figure 4-3. Fernald DoE Site, Ross, Ohio**



## 4.2 SITE GEOLOGY/HYDROGEOLOGY

### AF Plant 44, Tucson, AZ

The Tucson Basin is a broad, northwest-trending alluvial valley encompassing approximately 750 square miles in Pima County. AFP44 is situated at the western margin of the Tucson Basin. The Tucson Basin is located in the Alluvial Basin Hydrogeologic Province and the Basin and Range Geologic Province. These provinces are characterized by alluvial material that consists of clays, silts, sands, and gravels that eroded from the mountains and filled the basins. The coarser material is generally found near the mountains, while the finer material is found toward the center of the basins. Discontinuous layers of sand and gravel are encountered toward the center of the basins and probably represent ancient stream sedimentation.

The mountains bounding the Tucson Basin consist of crystalline igneous, metamorphic, and sedimentary rock. Geologists assume that AFP44 is underlain at great depths by crystalline rock consisting of granite, granite-gneiss, schist, andesite, basalt, and limestone that make up the mountains adjacent to the basin.

Several thousand feet of alluvial sediments deposited in the Tucson Basin are interbedded locally with volcanic flow, agglomerates, and tuffaceous sediments. The alluvial sediments that underlie the site have been characterized as belonging to four groups, which in descending stratigraphic order are surficial deposits, Fort Lowell Formation, Tinaja Beds, and the Pantano Formation.

The general hydrogeology beneath AFP44 includes a shallow perched groundwater zone (SGZ) and a regional aquifer (**Figure 4-4**). Within the regional aquifer at AFP44, there is an upper zone and a lower zone that are separated by a clay aquitard. Within the upper zone, there is an upper unit and a lower unit that are also separated by a clay aquitard. These units pinch out to the north and west and are therefore not hydrogeologically significant in the vicinity of AFP44.

The SGZ is comprised of partially saturated silty clay, identified in the northwest portion of AFP44 and comprising an estimated 70 to 100 acres. The SGZ consists of a highly heterogeneous, complex region of inter-layered sandy clay and clay with numerous thin lenses of sand and gravel. Vertical migration of fluid is restricted by a distinct clay aquitard between the SGZ and underlying upper aquifer zone.

The upper aquifer zone, located in the Fort Lowell Formation, consists of gravelly sand with some clayey sand and sandy clay to a depth of 200 feet below ground surface (bgs) and ranges in thickness from approximately 60 to 100 feet. This zone is underlain by a relatively impermeable layer of clay and sandy clay. The clay layer ranges in thickness from 100 to 160 feet and restricts the movement of groundwater between the upper and lower aquifer zones. Groundwater occurs in this upper zone under unconfined to semi-confined conditions.

The lower aquifer zone is located in the Pantano Formation and consists of clayey sand with lenses of gravelly sand and sandy clay. The top of the lower aquifer zone is approximately 300 feet bgs. Groundwater occurs in the lower zone under semi-confined conditions.

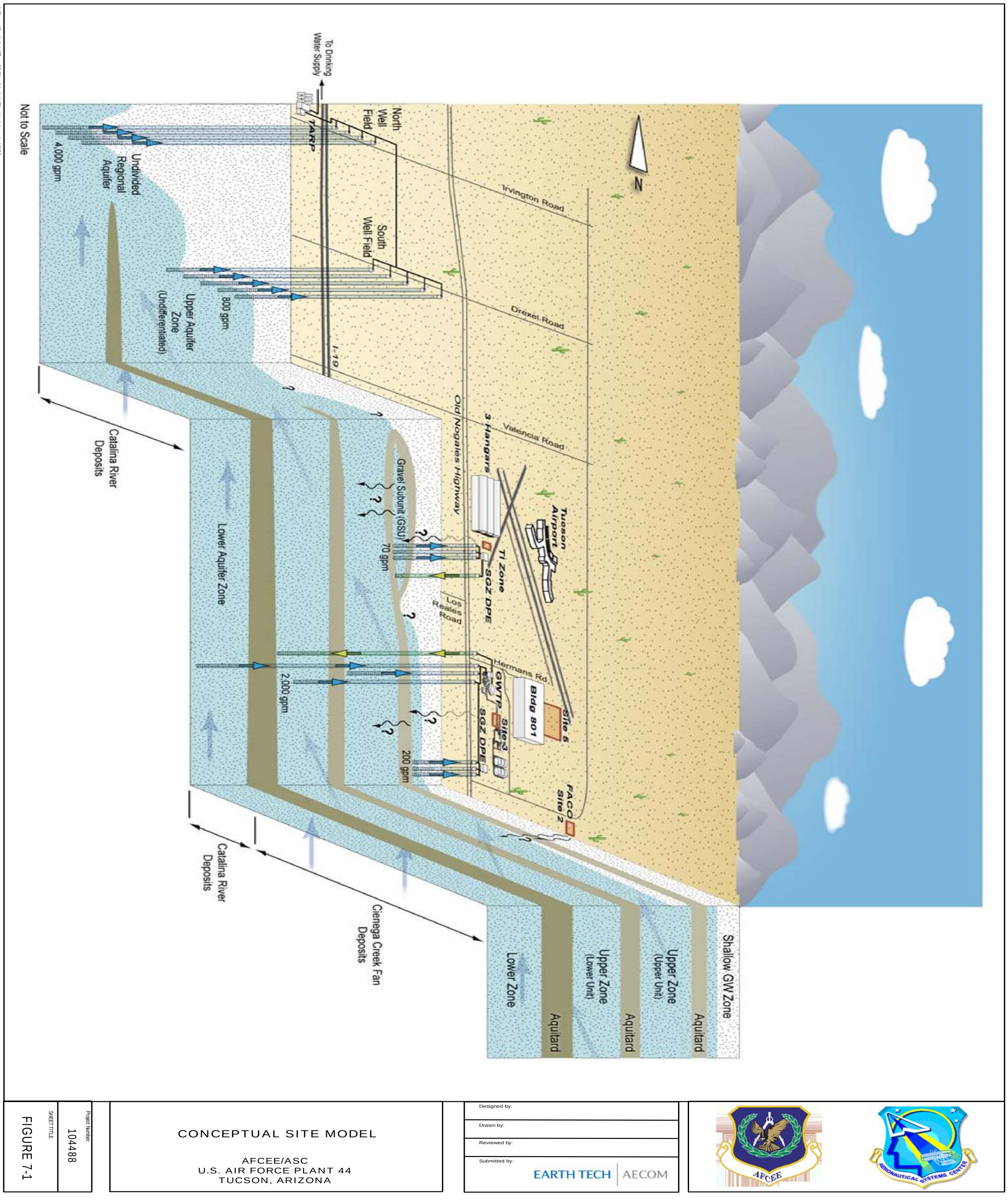



**Figure 4-4. Conceptual Site Model at AFP44**

**NOP, Mead, NE**

The NOP site is located in the Todd Valley, an abandoned alluvial valley of the ancestral Platte River. The thickness of the unconsolidated material above bedrock in the Todd Valley at the site ranges from approximately 81-157 feet. The unconsolidated material consists of topsoil, loess (predominantly wind-blown silt), sand, and gravel of Pleistocene age. The uppermost bedrock unit is the Omadi Shale in the northwest and the Omadi Sandstone in the southeast portions of the site.

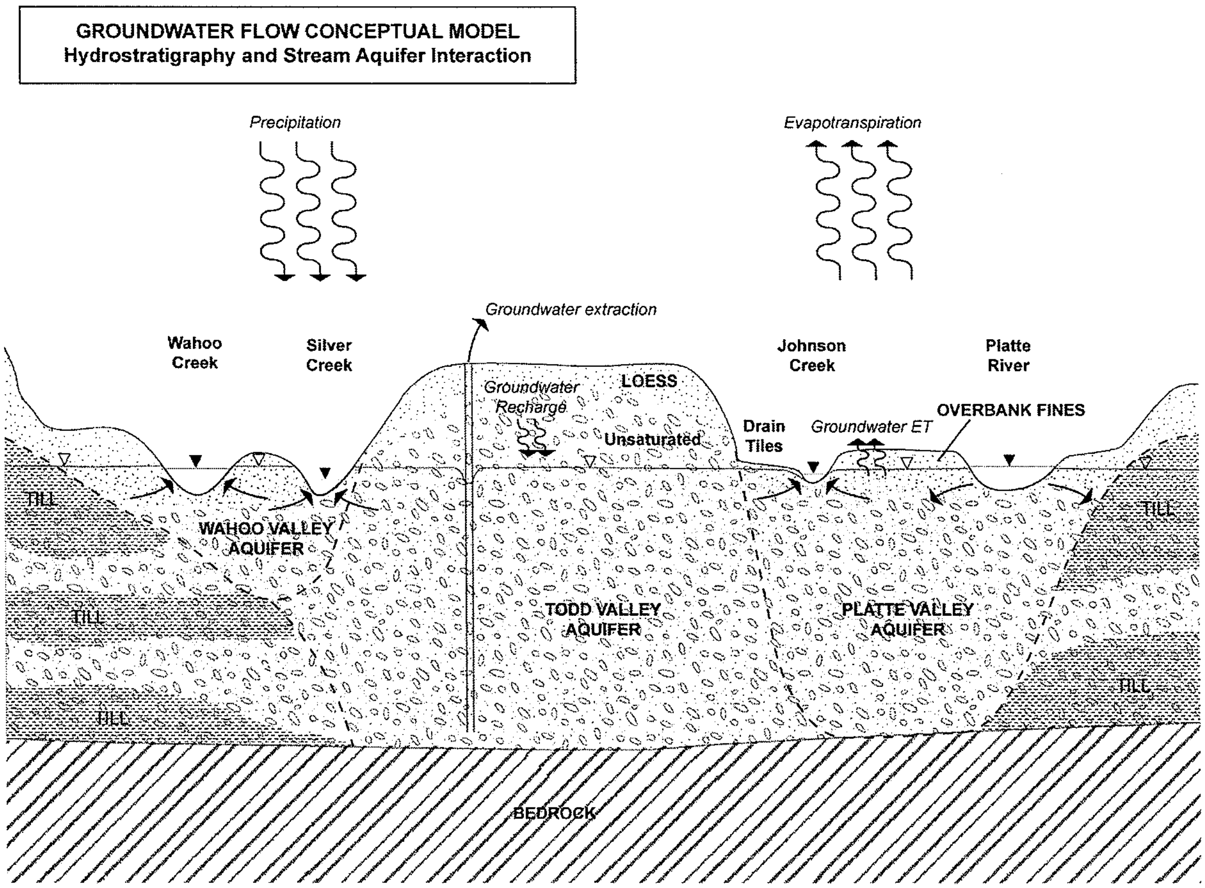
Three aquifers are present at the site: the Omadi Sandston aquifer, the Todd Valley aquifer, and the Platte River alluvial aquifer (**Figure 4-5**).

The Todd Valley aquifer is the first aquifer beneath the site. Towards the Platte River (i.e., towards the east) it grades horizontally into the Platte River alluvial aquifer. The Omadi Sandstone underlies these aquifers, and is part of the bedrock.In places, the Omadi Shale aquitard separates the deeper Omadi Sandstone aquifer from the overlying aquifer(s). Where the Omadi Shale is absent, the Todd Valley aquifer and the Platte River alluvial aquifer are in hydraulic communication with the Omadi Sandstone and behave as a single aquifer without hydraulic barriers. The Pennsylvania Shale aquitard underlies the Omadi Sandstone aquifer.

Monitoring well locations at the site were established based on regional groundwater flow (generally towards the south and southeast). The water-bearing portions of the unconsolidated material in the Todd Valley are divided into an upper fine sand unit (12-17 feet thick) and a lower sand and gravel unit (17.5-72 feet thick). The upper sand unit is overlain by 4-23 feet of Peoria Loess. The unconsolidated material in the Platte River Valley (i.e., in the immediate vicinity of the Platte River) ranges in the thickness from 39 to 49 feet. Overbank silts and clays ranging from 10-17 feet thick overlie the Platte River alluvial sands and gravels.

The water table surface of the Todd Valley slopes toward the south-southeast with depths to groundwater in the Todd Valley ranging from 6.6 feet to 58.0 feet. A local zone of groundwater discharge is located along the western side of the Platte River floodplain in the southeastern portion of the Site. East of Johnson Creek, the water table surface of the Platte River alluvial aquifer slopes to the south, paralleling the Platte River Valley with depths to groundwater in the Platte Valley ranging from 0.0-10.2 feet.

**Figure 4-5. NOP Conceptual Site Model**




## Fernald, Ross, OH

A map of the Fernald groundwater aquifer zones is presented in **Figure 4-6**. The former production area occupied approximately 136 acres in the center of the site. Paddy's Run flows north to south along the western boundary of the site. The Great Miami River flows generally north to south to the east of the site before turning to the southwest south of the site. The site is situated on top of glacial overburden, consisting primarily of clay and silt with minor amounts of sand and gravel that overlies the Great Miami Aquifer. The Great Miami Aquifer itself contains a non-continuous clay interbed that separates the Great Miami Aquifer into an Upper and Lower portion.

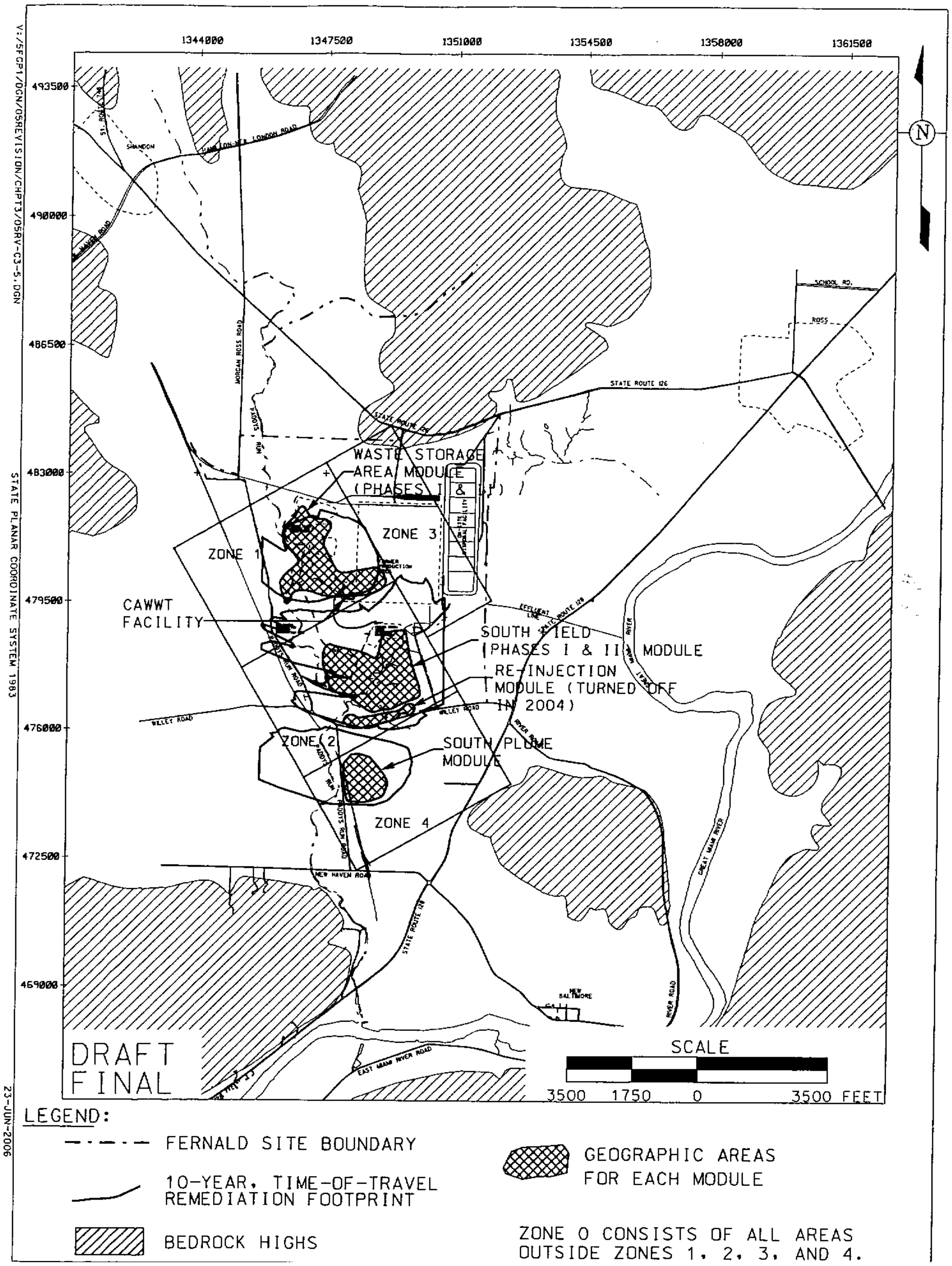
The Great Miami Aquifer is underlain by shale inter-bedded with limestone. Paddy's Run has eroded the glacial overburden, exposing the sand and gravel that make up the Great Miami Aquifer. Groundwater flow in the Great Miami Aquifer, in general, is to the east, southeast, and south across the facility, towards the Great Miami River.

The Fernald Site is located within a buried valley glacial outwash aquifer system, covered by younger glacial overburden. There is a perched groundwater system contained within this glacial overburden. The overburden is composed principally of clay-rich till having a sustainable

groundwater yield of approximately 1 gallon per minute. Horizontal flow is substantially greater than vertical flow, ranging from 1 to 58 feet per year horizontally but only 0.85 to 2.15 feet per year vertically.

The main aquifer consists primarily of well-sorted sand and gravel material. It has a sustainable yield of 400 gallons per minute, with horizontal flow ranging from 400 to 1000 feet per year.

**Figure 4-6. Fernald Groundwater Aquifer Zones**



## 4.3 CONTAMINANT DISTRIBUTION

### AFP44, Tucson, AZ

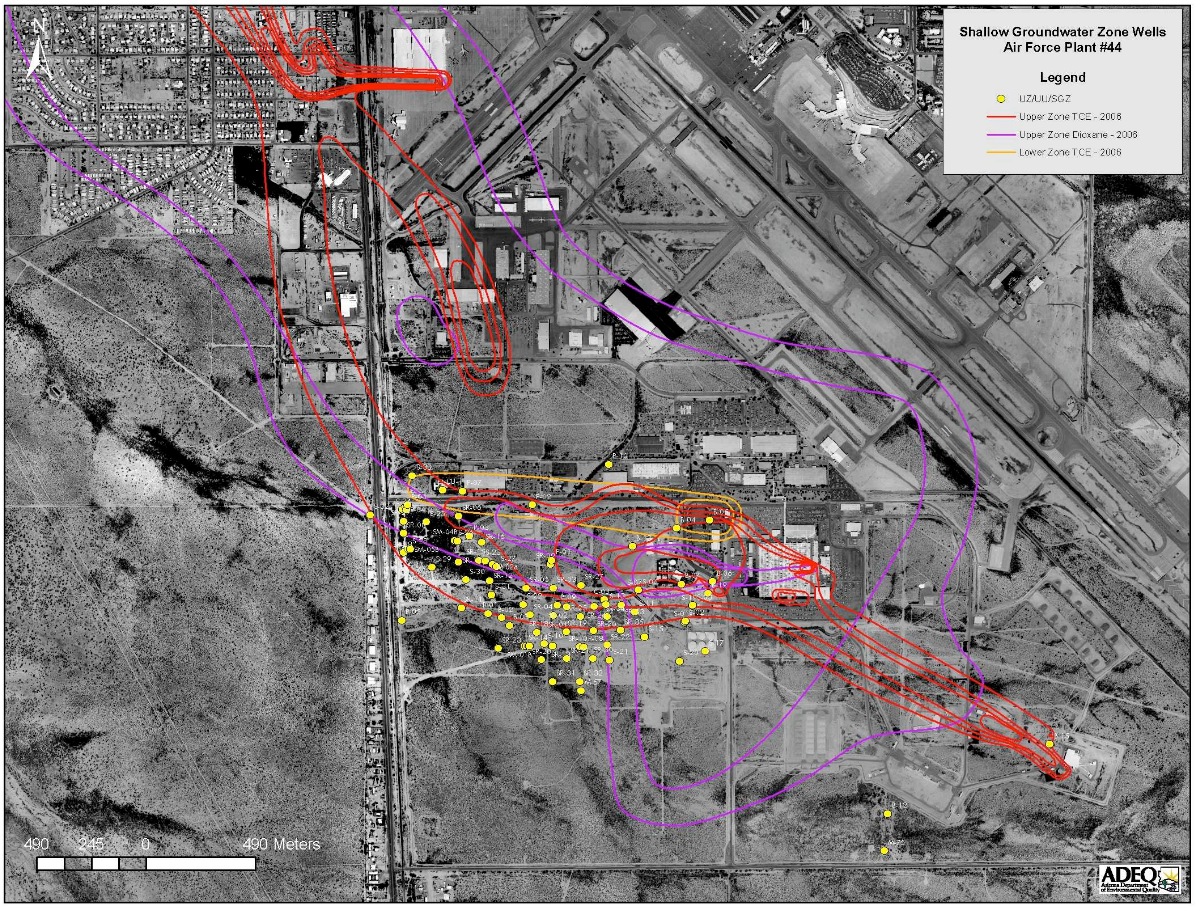
The extent of contamination at AFP44 is described in the comprehensive Human Health Risk Assessment for 1,4-Dioxane in Groundwater (HHRA) that was completed in 2004. It related to 1,4-Dioxane at AFP44, but also addressed potential risks to receptors north of AFP44 within the footprint of the 1,4-Dioxane plume in the regional groundwater. See **Figure 4-7** for a map of plume extent.

Prior to detection of 1,4-Dioxane in groundwater, three contaminants had been detected in groundwater at levels that exceeded either promulgated groundwater standards or human health risk-based criteria — these included TCE, 1,1-DCE, and chromium (total). Concentrations of other chemicals, including degradation products of TCE, 1,1-DCE, and 1,1,1-TCA, were infrequently detected at concentrations below respective screening criteria. The area downgradient of AFP44 also has TCE and 1,1-DCE contamination in regional groundwater above 5 and 7 ppb, respectively, that covers the area north-northwest to approximately Irvington Road. A groundwater containment system is already in place at AFP44 to reduce or eliminate off-site migration, thereby managing these chemicals of concern (COCs).

1,4-Dioxane, a stabilizer for 1,1,1-TCA, has also been identified in groundwater in the vicinity and downgradient of AFP44. Drinking water extraction wells operated by the City of Tucson are located within the downgradient area of contamination. Groundwater is treated through an air stripping system prior to its distribution in the City of Tucson water supply. The City of Tucson has stated that all water supplied to the community through their water system will be at or below 3 ppb for 1,4-Dioxane.

As an emerging contaminant, since the completion of the HHRA, additional investigations of 1,4-Dioxane in the vicinity of AFP44 and downgradient of AFP44 have taken place and have found the levels ranging from non-detect to 11 ppb in 2006, from non-detect to 16 ppb in 2007, and from non-detect to 8.8 ppb in the spring of 2008. At AFP44 itself, a 2008 round of groundwater monitoring yielded 1,4-Dioxane results from 144 wells that ranged from non-detect to 1,400 ppb.

**Figure 4-7. Plume Extent at AFP44**




## NOP, Mead, NE

The following VOCs and explosive compounds were identified at the site (primary COCs are indicated with a "*"):

VOCs —

- Trichloroethene (TCE)*
- Methylene chloride (MC);
- 1,2-dichloropropane; and

Explosive compounds —

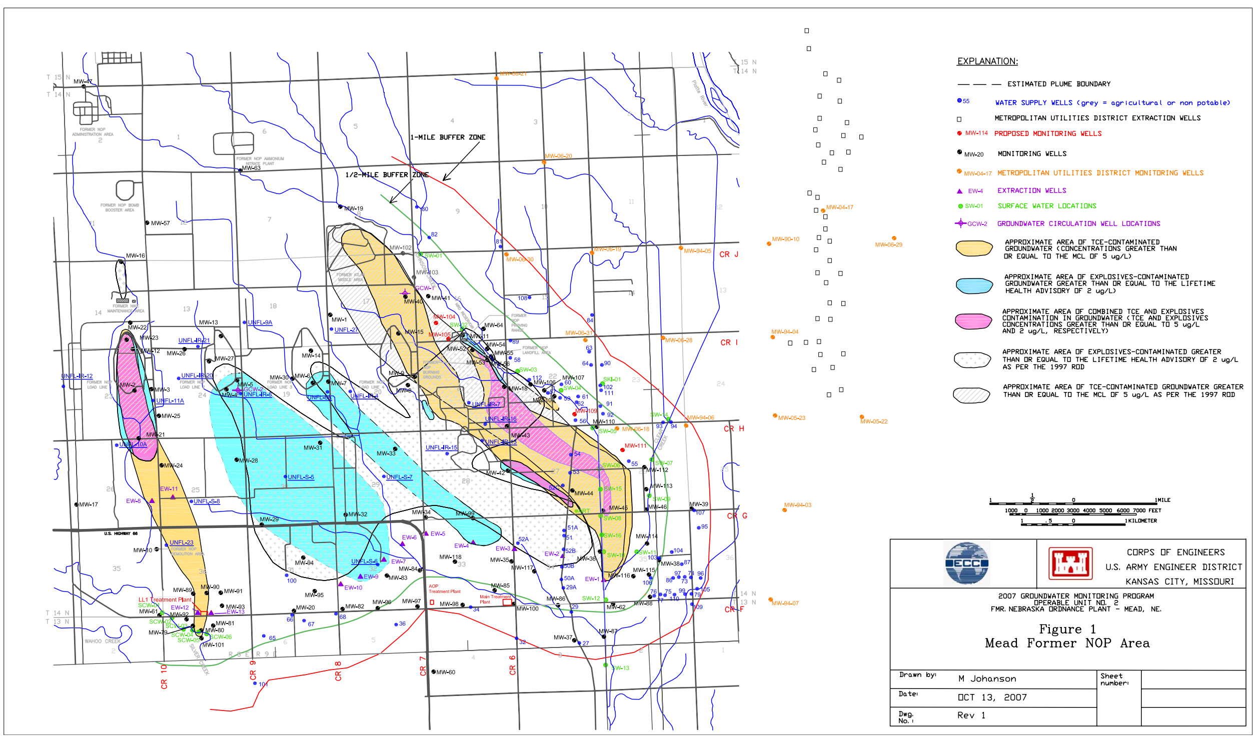
- Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)*
- 1,3,5-trinitrobenzene (TNB)
- 2,4,6- trinitrotoluene (TNT)
- 2,4-dinitrotoluene (2,4-DNT)

Site investigators generally distinguish plumes based on TCE and RDX (**Figure 4-8**). The four plumes (or "lobes") of groundwater contamination identified at the site include:

- TCE plume with suspected source from the Atlas Missile Area, which is north of the eastern load lines (LL3 and LL4);
- TCE plume with suspected source from Load Line 1 (LL1);
- RDX plumes with suspected sources from LL1, LL2, LL3, and LL4.

According to site reports, the migration of these contaminant plumes is dictated primarily by the southeastward direction of the groundwater flow. The TCE and RDX plumes overlap in two areas: LL1 and LL4. The overlap at LL4 is due to migration of TCE from the Atlas Missile Area. Higher groundwater contamination is found in the upper fine sand units than in the sand and gravel units below. Generally, lower contaminant concentrations are found in the deepest of the three aquifers (the Omadi Sandstone aquifer). Overall, the plumes at NOP are characterized by fairly low COC concentrations (i.e., ND-10 ppb). [Note: Due to the large number of non-detects and the small number of sampling events for numerous wells contained within the NOP input file, the independent analyst assigned to comparatively analyze the data using MAROS determined — in conjunction with Dr. Mindy Vanderford of GSI — that the data file was not suitable for MAROS analysis.]

**Figure 4-8. NOP Plume Extent**



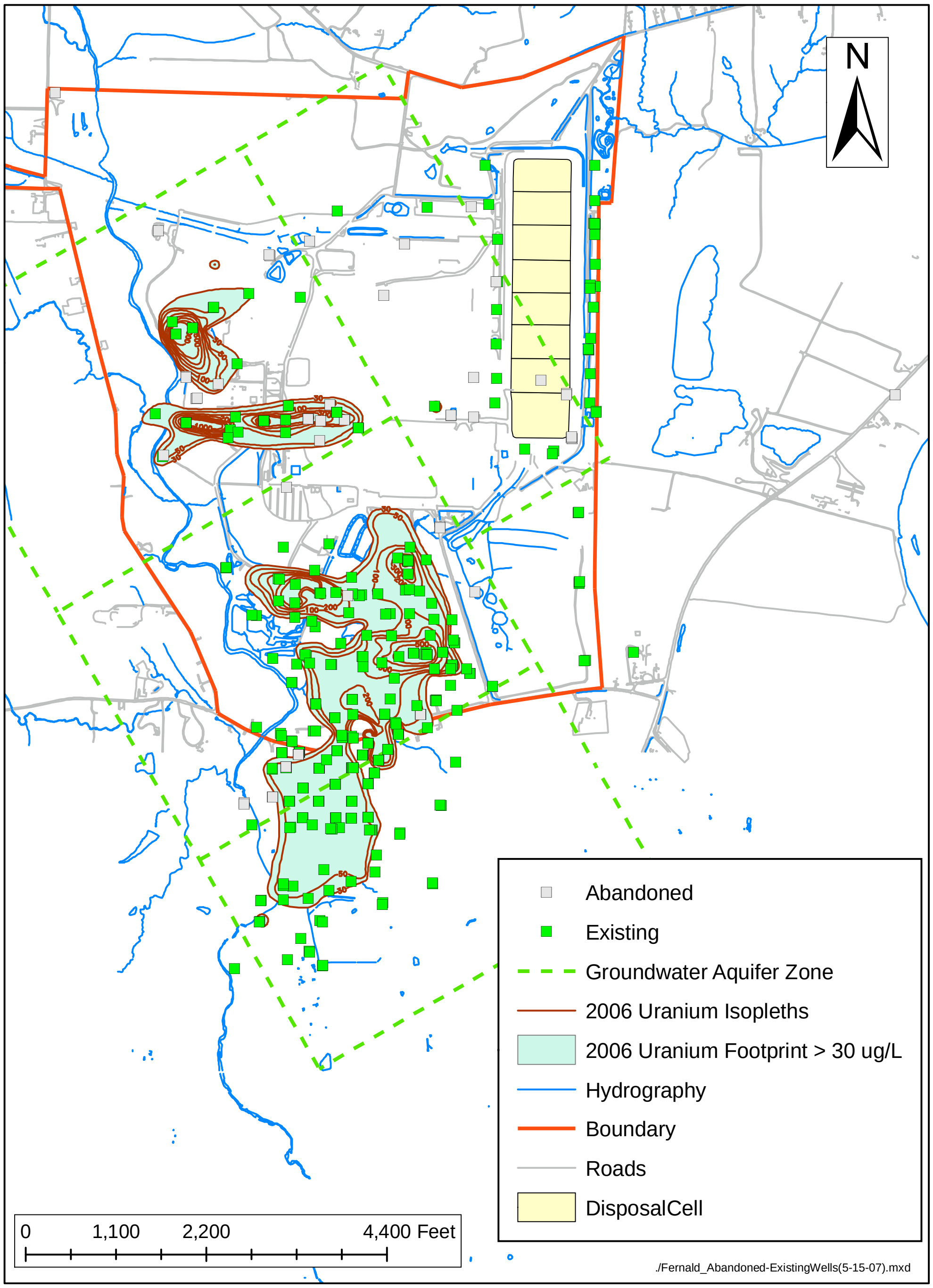
## Fernald Site, Ross, OH

The primary contaminant (COC) at the site is dissolved uranium, consistent with historic operations at Fernald. As noted, the site produced high purity uranium metal from 1952 through 1989. During that time period a significant amount of uranium was released to the environment, resulting in contamination of soil, surface water, sediments, and groundwater on and around the site. While there were other contaminants of concern besides uranium, uranium was by far the most significant and extensive contaminant of concern in environmental media, including groundwater.

During the 1990s and early 2000s, site remediation took place. High-level wastes were shipped off-site for disposal. Low-level contaminated material including building debris and soils were placed in an on-site disposal facility constructed for that purpose. The remediation process included deep and extensive excavations to remove soils contaminated with uranium that were believed to be sources for observed uranium groundwater contamination.

Groundwater contamination of the Great Miami Aquifer is believed to have resulted from infiltration of contaminated surface water through the bed of Paddy's Run, the storm sewer outfall ditch, the Pilot Plant drainage ditch, and the waste storage area ditch. In addition, groundwater contamination resulted from the emplacement of uranium-contaminated wastes in disposal areas such as the South Fields, and subsequent uranium leaching. There is no significant groundwater contamination of the underlying bedrock. Uranium contamination is not uniformly distributed over the vertical profile of the Great Miami Aquifer. In general contamination levels are highest in groundwater associated with the water table in the vicinity of original source areas, with the center of mass of uranium contamination becoming deeper as one moves down gradient with the plume, reflecting vertical gradients in groundwater flow and recharge of clean groundwater from infiltration through uncontaminated soils down gradient of old source areas (**Figure 4-9**).

**Figure 4-9. Uranium Extent at Fernald**



# 5.0 TEST DESIGN

This section provides an overview of the testing design for this ESTCP project. Additional details are presented in the appendices devoted to the three demonstration site case studies:

- **Appendix B** — Air Force Plant 44 Site
- **Appendix C** — NOP Site
- **Appendix D** — Fernald Site

These appendices include optimization results for each site, as well as verbatim reports from the independent site analysts who utilized the same data sets as the ESTCP project team.

## 5.1 CONCEPTUAL EXPERIMENTAL DESIGN

The following general approach was applied at each of the three demonstration sites:

- The ESTCP project team obtained preliminary approval and information from the site for review prior to site visit (including relevant descriptive reports and preliminary electronic data if available).
- The ESTCP project team conducted a site visit to present an overview of the GTS software and the project, and to receive input from the site on specific issues/characteristics that might impact the optimization strategy. This input included overviews of the Conceptual Site Model (CSM), data availability and format, contaminant drivers, and a tour of the site area.
- After discussion of the types of data needed to run a GTS analysis, the site and/or its contractors provided the ESTCP project team with the most updated version of historical sampling data in electronic format. This included not just analytical concentration data, but also site boundary information, and available water level data.
- Upon receipt of the electronic data, the ESTCP project team prepared the data for use in GTS. This preparation required the following steps:
    - Data screening and exploration — all historical concentration and water level data were examined for inconsistencies and obvious data quality issues. Significant questions or issues with the data were addressed to the site for possible resolution.
    - Data standardization — field names in the site data were standardized and matched to the expected GTS field name inputs.
    - Reserving the most recent year of sampling data for use in the GTS Predict Module, in order to test the flagging of newer anomalous data against GTS baseline trend and plume estimates using the Trend and Plume Flagging features.

- Creating tab-delimited (text) versions of the analytical data file, boundary file, and water level file (if separate from the analytical data) that could be directly imported into GTS.

- The prepared and standardized site historical data was supplied to both the ESTCP project team and the mid-level analyst responsible for performing an independent GTS optimization at that site.
- Two independent GTS analyses were performed using the same standardized data package: one by the (expert) ESTCP project team and one by the (non-expert) mid-level site analyst. The mid-level analyst supplied the ESTCP project team with a write-up of their results and the GTS project files they generated.
- The ESTCP project team analyzed the reserved last year's data by feeding it into the GTS Predict Module. This was done to assess the functionality of the GTS trend flagging and plume flagging features. Summary reports were prepared of any anomalous data and the effectiveness of these techniques.
- Preliminary results of the optimization were communicated to representatives of the site, either via email/phone or in-person presentation (AFP44).
- Detailed comparison was made between the independent analyses conducted by the ESTCP project team and the mid-level site analyst, in order to assess GTS usability, functionality, and reproducibility. These comparisons are incorporated into this final report.

In addition to the general experimental design described above, the following activities were also performed:

1) To perform a 'layered' or 2.5D optimization analysis in GTS, each well location must have an aquifer zone designation. At AFP44, a number of wells either had uncertain designations or long well screens that traversed two aquifer zones as specified in the CSM. After consultation with site hydrogeologists, two versions of the AFP44 data package were prepared: one in which the uncertain wells were assigned to the uppermost of the possible zone designations and another in which these wells were assigned to the lowermost zone. Both variations of the data were analyzed by the ESTCP project team, while only one variation was supplied to the mid-level site analyst.
2) At the NOP site, a comparative study was performed by applying the Summit Tools and MAROS software applications, using the standardized data package for NOP. This was done to prepare a 'white paper' comparison between GTS, Summit Tools, and MAROS.
3) At the NOP site, the standardized data package had to be subsequently revised when the ESTCP project team discovered that approximately 2,000 of the analytical data records were essentially duplicates of other records. These duplicates were removed, a revised data package was sent to the ESTCP project team and mid-level site analyst, and the expert optimization analyses at NOP were re-done using the revised data.
4) At the Fernald site, a substantial number of the historical sampling locations involved Direct Push Technology (DPT), as opposed to other locations that were more permanent monitoring wells. To apply GTS to these data, closely-spaced DPT sampling events were relabeled as single 'wells' in order to create an approximate data history for each such location.

5) DoE arranged for its contractor to apply the GTS software to an additional site (Paducah, KY), and provided feedback to the ESTCP project team by preparing and submitting a summary report (see **Appendix E**). In addition, AFCEE arranged for the AFP44 data to be analyzed by two independent site analysts with differing levels of experience. Both of their summary reports are included in **Appendix A**.

## 5.2 BASELINE CHARACTERIZATION

At each demonstration site, optimization with GTS could only occur after first establishing a set of baseline conditions, especially since the redundancy analysis is predicated on comparing alternate and potentially optimal sampling programs against the initial baseline conditions. To establish an appropriate baseline, the following steps were conducted:

- Historical data acquisition and preparation
- Developing an optimization strategy
- Creating a set of estimated baseline trends and plume maps within GTS
- Estimating costs of the baseline monitoring program

Each of these steps is discussed in more detail below.

### Historical Data Acquisition and Preparation

The first critical step was to obtain historical data in electronic format from each site and to then prepare that data for import into GTS. This was done prior to actual testing of the revised software. Significant results or observations stemming from this process include:

- *Data Quality Review*. An initial review of data quality was imperative. The ESTCP project team found substantial numbers of missing or unavailable pieces of information in its initial requests for historical analytical measurements and water level data. Follow-up questions/requests for clarification and additional data were forwarded to each site representative. Data review included items such as consistency of well names, availability and consistency of x-y coordinates in a consistent coordinate system, consistency of reporting limits and method detection limits for non-detects, completeness of the electronic data, and the presence of duplicate records. The review also looked at consistency of screened depth intervals, aquifer zone designations, surface elevations, and the amount of available water level data. Furthermore, time series plots of the concentration data were made to determine if any wells exhibited unusual data histories that might reflect data quality problems. Although this step took several days of manual labor per site, it is necessary for application of any kind of LTMO software.
- *Input File Format*. Sampling data imported into GTS can have a variety of possible text delimiters separating the fields. However, tab-delimited format is recommended. The order of fields within a text data file is not important, but the field names must exactly match the list of acceptable names in the GTS users guide. Not all fields listed in the users guide are critical to GTS analysis, though fields that help locate each measurement within a Cartesian coordinate grid or that identify a measurement's

magnitude and type (i.e., detected, trace, non-detect) are. Also critical is the standard CAS number for each chemical contaminant. GTS matches the CAS number against its internal database to determine chemical-specific information such as standardized name, toxicity, mobility, and common regulatory limits. GTS also assumes, except for radiologic parameters, that all units have been standardized to parts per billion (ppb or ug/L) concentration, and that this designation is consistent across records for a given chemical.

- *Sampling Event Constraints*. Although a full optimization analysis in GTS requires at least 8 distinct sampling events, there is no requirement that these events be either evenly spaced or spaced at least, say, quarterly. It is also possible to have multiple sample measurements on the same chemical at the same well with the same sampling date (e.g., field or lab duplicates). Due to properties of the local regression mapping engine utilized by GTS, users are not forced to have only one measurement per location per sampling event, or to perform averaging or random selection of such data records. Furthermore, GTS automatically groups irregularly spaced measurements into discrete subsets representing non-overlapping periods of time. These discrete time intervals are the 'time slices' discussed in **Section 2.1**.

- *Rules for Non-Detects*. Non-detects are a persistent feature of groundwater monitoring data. To reasonably account for non-detect sample records, GTS requires the user to supply four fields: a strictly numeric measurement/concentration field ('PARVAL'), a 'PARVQ' field designating whether the sample is detected, non-detect, or a trace value, and fields for the method detection limit (MDL) and reporting limit (RL). Each of these fields is typically present within ERPMS-consistent databases, so the user does not need to further manipulate the data outside GTS. Within the program, a set of rules is followed in order to impute a value for each non-detect. Broadly speaking, non-detects with positive values in the PARVAL field are set to half that value on assumption that PARVAL contains a sample-specific reporting limit, while non-detects with zero or missing PARVAL are set to half the RL or MDL, whichever is present. Note: other laboratory or data quality flags can be imported into GTS, but are not used directly to impute non-detects. Instead, these flags can be examined by the user to help validate other information within the sample record.

- *Outliers*. During data preparation, the ESTCP project team screened each dataset for obvious data inconsistencies, something each user is encouraged to do prior to GTS import. However, within the program, GTS v1.0 provides two different algorithms for flagging potential outliers: temporal outliers and spatial outliers. Using these screening tools, users are able to tag and eliminate statistical discrepancies from subsequent analysis and optimization (including, for instance, 'dilution outliers' where a non-detect has an unrealistically high reporting limit due to multiple dilutions in the lab). The sample records flagged as outliers are not removed from the database, but simply removed from analysis. The user can also generate outlier reports to document which specific data records were not utilized.

- *Data Filtering*. To maximize user convenience during data preparation and to account for electronic 'data dumps' that tend to be inherently 'messy' from the perspective of

data screening, GTS provides a filtering mechanism within its internal database once a dataset has been imported. Although the viewing and sorting options within the database are somewhat limited, users can create complex, multi-level filters to significantly pare the data to be used during analysis. For this ESTCP project, almost all the initial screening was conducted outside the program, primarily to ensure that both the ESTCP project team and the mid-level site analysts would begin working with the same datasets. In more typical applications, filtering can provide a very valuable tool for winnowing data to a desired subset.

**Developing an Optimization Strategy**

The strategy for performing GTS optimization varied somewhat at each demonstration site, based on site-specific characteristics and contaminant drivers. However, GTS utilizes one guiding principle and one over-arching assumption in optimization. The critical assumption is that GTS will be applied to sites with potentially *too many* sampling measurements, rather than *too few*. With the exception of its network adequacy analysis and temporal variograms, GTS establishes optimality by *removing* data from the current monitoring system and identifying some portion of this data as redundant. It is therefore primarily designed to establish optimality by eliminating analytical data redundancy.

The related guiding principle is that redundancy can best be discovered by comparing concentration trends and maps estimated from the full (non-optimized) data against corresponding trends and maps constructed from reductions in the data (i.e., reduced-data sets). Reduced-data trends and maps that are identical or very similar to their full-data counterparts indicate the presence of redundancy, while significantly different trends and/or maps suggest that critical data has been lost during reduction.

Significant results and observations about this process include the following:

- *Numbers of Contaminant Drivers*. The number of critical COCs varied by site, based on the input and feedback of site personnel. At Fernald, the only key driver was uranium; this COC constituted by far the bulk of the raw dataset. No other parameters were sampled more than sporadically or at more than a few wells. At AFP44, the database was pre-selected by site contractors to include four key COCs: chromium, TCE, 1,4-Dioxane, and 1,1-DCE. All four were considered to have widespread presence in groundwater and to thus be contaminant drivers, though 1,4-Dioxane was not sampled in every aquifer zone. At NOP, seven contaminants were part of the database, including 3 explosives and 4 VOCs. NOP site representatives asserted that only two of these COCs were actual contaminant drivers: TCE and RDX. Results of the GTS COC ranking analysis at NOP bore out this assertion. TCE and RDX were judged by GTS to have the best optimization potential of any of the chemicals.
- *COC Ranking and Optimization Constraints*. To minimize overall computing time and resources, GTS currently sets an upper bound to four on the number of COCs that can be simultaneously optimized. Obviously, this maximum is arbitrary, but reflects the fact that most sites have only a handful of key contaminant drivers. Contaminants in datasets with larger numbers of COCs are screened and ranked using the GTS Explore Module, specifically the COC ranking analysis. This analysis develops a ranking of optimization potential for each COC, based on factors such as the areal

extent and frequency of sampling, rates and areal extent of both detections and exceedances above regulatory limits, sample sizes in the database, and mobility and toxicity factors. In practice, the COC ranking analysis can be used to identify those contaminant drivers that are most useful for optimization. During the ESTCP demonstration, the COCs to be optimized were already pre-set by site personnel at Fernald and AFP44. At NOP, however, the ranking analysis was applied to all 7 database contaminants; TCE and RDX not only emerged as the highest ranked COCs, but their ranks were substantially higher than any of the other contaminants. Consequently, only these two drivers were optimized (see **Table 5-1**) by the ESTCP project team. Note, however, that the NOP independent site analyst also optimized both TNT and Methylene Chloride (MC) in his final analysis (due to a software glitch that has since been corrected).

**Table 5-1. COCs Used During GTS Optimization by ESTCP project team**

| Site | COCs Optimized |
|---|---|
| **AFP44** | TCE, Chromium, 1,4-Dioxane, 1,1-DCE |
| **NOP** | TCE, RDX |
| **Fernald** | Uranium |

- *Evaluation of Multiple COCs*. Because multiple contaminant drivers may be present, GTS can optimize multiple COCs (up to a maximum of four) simultaneously, either during redundancy analysis or when assessing network adequacy (i.e., need for new well locations). To accomplish this during temporal optimization, GTS computes an optimal sampling frequency for each COC (either per-well, per-aquifer zone, or per-site) and then computes the median optimal sampling frequency across the COCs. In spatial optimization, a critical index is computed for each distinct well location by computing the fraction of COC-time slice pairs in which that well was deemed 'critical' to the network (i.e., non-redundant). If the overall critical index is less than 0.5 after all COCs have been analyzed, that well is flagged as redundant. When analyzing network adequacy, GTS computes and maps a unitless uncertainty index for each COC across the site based on coefficients of variation. New wells are only suggested at locations where multiple COCs exhibit high levels of uncertainty.
- *Evaluation of Multiple Aquifer Zones*. Because distinct aquifer zones may exhibit very different concentration patterns and thus distinct plume maps, GTS can analyze multiple aquifers or aquifer zones simultaneously during a given spatial optimization run. To do this, the user must either select a 2D (i.e., two-dimensional) or 2.5D (i.e., two-and-a-half dimensional) approach at the end of the Explore Module, and prior to creating base-maps. The 2D option treats all well locations as if screened in a single aquifer or layer. Plume maps generated under this option thus approximate the

concentration distribution across a single, horizontal plane. The 2.5D option by contrast allows for multiple, distinct aquifer layers to be analyzed sequentially, with separate maps and optimization results generated for each layer. The user does not need to segregate the data by aquifer layer or go outside the program to perform a full analysis; rather, the sorting, analysis, and concatenation of results across layers is done automatically within GTS.

- *Multiple Zones at Demonstration Sites*. The same optimization strategy was pursued by the ESTCP project team and mid-level site analyst at the AFP44 and NOP sites. In each case, the 2.5D option was selected, due to the presence of multiple, distinct aquifer zones (note: the second site analyst at AFP44 selected a 2D analysis for comparative purposes). At the NOP site, each of the SHALLOW, MEDIUM, and DEEP aquifers was analyzed, with substantially different levels of spatial redundancy. At AFP44, the layering was more complex and less distinct. The topmost layer (Shallow Groundwater Zone [SGZ]) only extends across part of the site, while the next layer (Upper Zone) is divided into an upper (UZUU) and lower unit (UZLU). Furthermore, the deep Lower Zone (LZ) only contains a small number of screened intervals, making it difficult to perform a GTS spatial analysis on just that layer. As a consequence, both the mid-level site analyst and the ESTCP project team chose to combine the Lower Zone and the Upper Zone Lower Unit into a single aquifer layer for purposes of the analysis (LZ-UZLU). GTS includes a feature that allows such merging of aquifer horizons (as well as deletion of certain layers or unmerging of combined layers) within the program, without any alteration to the raw data. In sum, both of these sites were optimized using a 2.5D (layered) analysis, each with three distinct aquifer zones.

  The Fernald site was exceptional in two ways: (1) based on initial input from site representatives, the hydrogeology at various depths was not considered distinct enough to warrant a 2.5D analysis. Indeed, within the raw electronic data, only a small percentage of the records were distinguished by aquifer zone; the vast majority did not contain an aquifer designation. Consequently, the ESTCP project team analyzed Fernald as a 2D, single layer optimization. (2) unknown to the ESTCP project team, the mid-level site analyst at Fernald retrieved additional information from the site and subsequently ‘filled in’ the missing aquifer zone designations, thus editing and altering the standardized data package that had been prepared. The analyst then proceeded to run both a 2D analysis and a 2.5D optimization, using the filled-in zone designations, in order to perform a sensitivity analysis. Of interest, the site analyst’s report (**Appendix D**) indicates that concentration levels of uranium in the three most populated aquifer layers were quite similar, somewhat buttressing the choice of a 2D analysis. More discussion of these differences can be found in **Section 5.5.5**.

- *Multiple Plumes within an Aquifer*. Unlike MAROS and similar software, GTS does not use or require plume-specific information such as locations of source areas, or designations as to which wells monitor the source or the tail of the plume. Instead, GTS is designed to estimate a concentration map across the entire site area of interest (as indicated by either the convex hull around the observed well locations or a separate boundary file imported by the user). GTS is thus able to estimate multiple

plumes (and/or hot spots, source areas, etc) within a bounded region. This feature was needed at the demonstration sites, since in each case, for at least one of the contaminant drivers, there were either multiple plumes (uranium at Fernald; TCE and RDX at NOP) or multiple lobes off the same plume (TCE and 1,4-Dioxane at AFP44).

- *Measuring Plume Error*. With any spatial mapping algorithm, discrepancies or errors will occur between the actual concentrations at unmeasured locations and the corresponding map estimates. The goal, of course, is to minimize this error, but inevitable tradeoffs occur depending on how error is measured and/or weighted. With QLR — the mapping engine in GTS — an additional source of potential error occurs at *measured* locations since QLR is a smoother and not an interpolator like kriging. To gauge the accuracy of a base-map, GTS considers the weighted errors or residuals between map *estimates* at known locations and the *observed concentrations*. However, GTS also assumes that the absolute magnitudes of errors in high-concentration areas (e.g., plume interiors) are not as critical as similarly sized errors in low-concentration areas (e.g., near plume or site boundaries). Therefore, GTS computes by default a kind of relative residual, in particular, the logarithm of the ratio between the map estimate and the corresponding 'known' concentration. By computing residuals in this manner, less statistical weight is placed on larger discrepancies in high-valued areas, while more weight is given to significant discrepancies in low-valued regions.

  GTS also differentially weights the relative residuals according to the spatial density of the measured observations. Observations in more sparsely sampled areas are given greater statistical weight due to the fact that they inform a relatively larger share of the site areal extent, while observations in clustered locations individually receive lesser weight. Computation of these weights is achieved by computing the ratio of the area of the Voronoi polygon associated with each measured location divided by the total site area.

- *Protected Wells*. In developing an optimization strategy for each site, the ESTCP project team requested input from site personnel as to whether any well locations should be 'protected' (i.e., excluded) from a redundancy search. These protected wells are always kept in the optimized sampling program, regardless of what happens to other locations. The NOP site requested that 77 locations, mainly site boundary wells, be protected from GTS optimization. At AFP44, only 2 wells were so designated. None were suggested by Fernald personnel; however, in reviewing information provided by the site, 91 of the 467 distinct locations (mostly monitoring wells) had been abandoned by the time of the ESTCP demonstration, yet still had valuable historical data. To account for this status and to avoid flagging an already abandoned well as 'redundant,' those 91 locations were labeled as protected for purposes of GTS analysis.

  To protect wells in GTS, there are two possible methods: (1) the user can add a binary field to the data file outside the program ('PROTECT_FLAG') and prior to data import; well locations with value 1 in this field are then treated as protected while those with value 0 are eligible for optimization; or (2) the user can designate selected wells as protected *within* GTS, via a series of checkboxes when viewing the baseline

network status display. The first method was utilized for all three sites during data preparation and standardization, in order to ensure that the same data structure was utilized both by the ESTCP project team and the mid-level site analysts.

- *Temporal Optimization Strategy*. GTS offers two different temporal strategies to accommodate varying monitoring networks and data configurations. Temporal variograms identify the sampling lag associated with a lack of event-to-event correlation. Samples collected at smaller (shorter) lags exhibit correlation and hence some statistical redundancy. Despite this straightforward idea, accurately estimating the inter-event correlation at a single well generally requires a significant amount of sampling data. To get around this limitation, GTS pools data from multiple wells into a single, average per-well event-to-event correlation estimate. In practice, this estimate is sensitive to fractions and patterns of non-detect measurements, so that temporal variograms do not always clearly identify a range (i.e., the smallest sampling lag associated with zero inter-event correlation). Because of this difficulty, users are encouraged where possible to first consider the other GTS temporal strategy, iterative thinning. Iterative thinning is performed by necessity on each individual well; it also requires at least eight distinct sampling events per location in order to estimate the baseline trend. From that baseline, data are 'thinned' at random (i.e., reduced) to assess the degree of redundancy and ultimately an optimal sampling interval.

  For this ESTCP project, sites were purposely sought with enough historical data to allow a temporal redundancy search by either of the two methods within GTS. This requirement, along with the GTS recommendation to use iterative thinning where feasible, led each site analyst to perform and report iterative thinning as the primary temporal optimization tool. For its part, the ESTCP project team ran both methods at each site to compare the results. More generally, some sites using GTS may not have enough historical sampling data to make iterative thinning feasible. In these cases, temporal variograms can often still be calculated (due to the pooling of data across multiple well locations), though there is no guarantee that a clear range will be identified.

**Creating A Set Of Estimated Baseline Trends And Plume Maps Within GTS**

The third step in baseline characterization was to create the baseline trends and base-maps by which GTS gauges redundancy. Since almost all redundancy and, hence, optimality in GTS is assessed by numerical comparisons against the baseline trends and base-maps, it is critical that the baseline estimates be consistent with the temporal and spatial patterns observed within the measured data. To ensure this, GTS utilizes non-linear local regression as its fundamental estimation engine: 1-dimensional regression for trends and 2-dimensional regression for maps. Non-linear local regression can generate realistic (concentration) estimates for a variety of complex data patterns, both temporal and spatial, including such examples as seasonality and local 'hot spots.' GTS also attempts to make good default choices in order to parameterize each local regression model. In the event the defaults do not lead to reasonable models, the software provides diagnostic tools to enable the user to adjust the model for a better fit. Significant results or observations stemming from this process include:

- *Removal of Data Gaps in Trend Estimation*. One of most significant challenges for local regression is fitting a reasonable trend during periods of time when there are large gaps between measured sampling events, e.g., when a well is not sampled for a few years prior to new sampling. Attempts to extrapolate a local trend to these gaps may result in wildly inaccurate estimates. To avoid these difficulties, GTS attempts to identify any substantial data gaps and to then exclude data prior to such a gap from trend estimation. Significant data gaps were identified for certain wells at each of the three test sites, suggesting that irregularly-spaced sampling is the norm rather than the exception in groundwater monitoring networks. Users are also encouraged within GTS to examine time series plots of contaminant-well pairs with potential gaps to make sure the gaps are visually substantial; any inconsequential gaps can be easily overridden prior to trend estimation.

- *Classification of Trend Types*. Unlike simple linear regression, building an accurate model using non-linear local regression requires additional data. To ensure that only those contaminant-well pairs with sufficient data are fit by local regression, GTS classifies each possible trend as either LWQR (local regression), Theil-Sen (non-parametric linear trend), FLAT (all measured values constant), FLAT-ND (all sampled values non-detects), or INSUFFICIENT (not enough data). No trends are fit to FLAT or FLAT-ND cases (due to lack of data variability), or in cases with less than 4 sampled values (INSUFFICIENT). For contaminant-well pairs with 4 to 7 measurements, non-parametric linear trends are constructed using the Theil-Sen method, and for all the rest with eight or more measurements, non-linear local regression is utilized. **Table 5-2** below lists the number of trends at each site classified by type.

**Table 5-2. Numbers of Trends Classified by Type at Demonstration Sites by ESTCP Team**

| Site | # Insufficient | # Flat or Flat-ND | # Theil-Sen | # LWQR | Total |
|---|---|---|---|---|---|
| **AFP44** | 99 | 113 | 97 | 342 | 651 |
| **NOP** | 57 | 295 | 53 | 57 | 462 |
| **Fernald** | 209 | 13 | 28 | 217 | 467 |

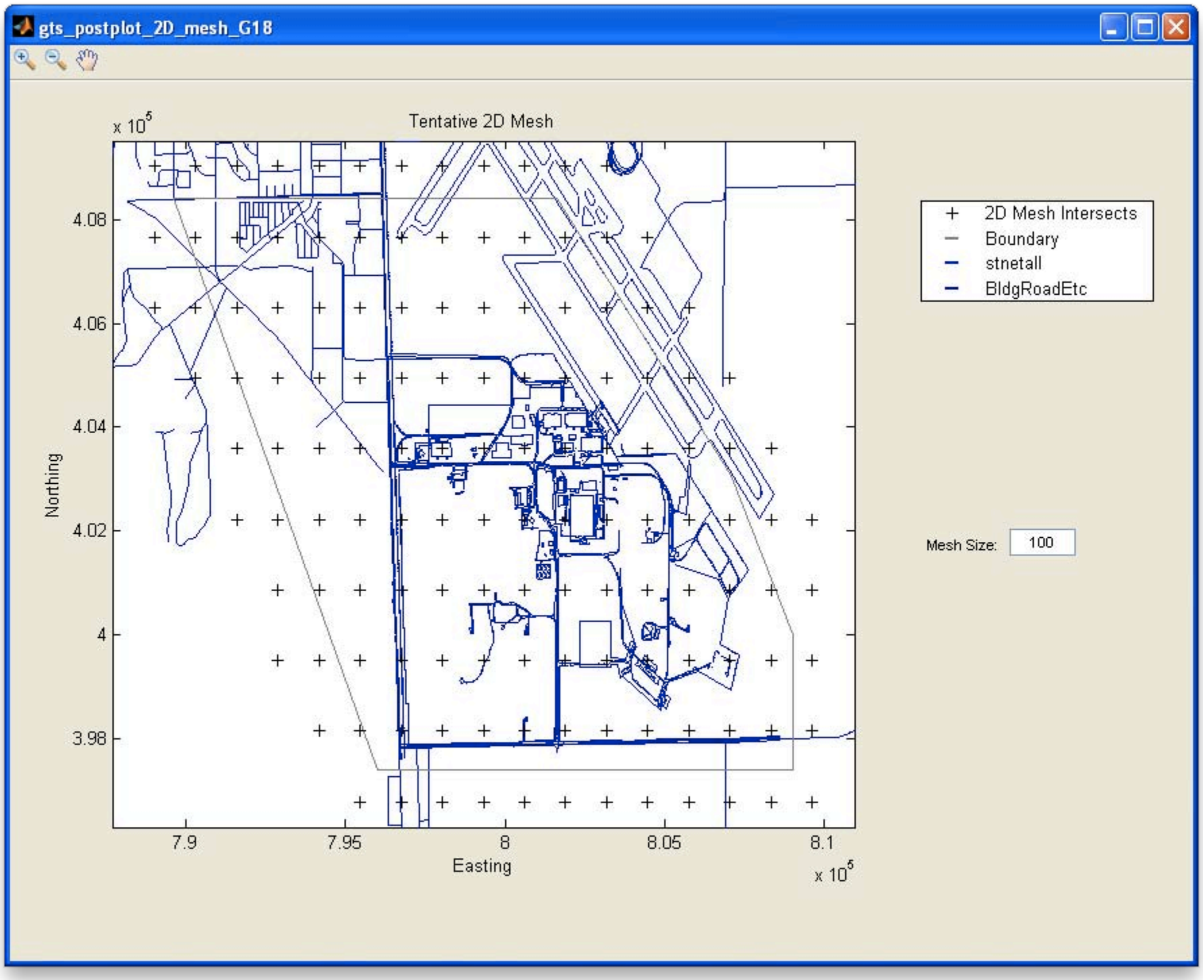
- *Trend Bandwidth Selection*. Any local regression model requires selection of a bandwidth parameter prior to fitting. GTS computes a default bandwidth value for each model based on internal checking of the residuals resulting from a range of alternate bandwidths. Despite this, perhaps due to unusual data clustering or general data sparseness, the default bandwidth may lead to highly inaccurate trend estimates over one or more portions of the date range. The bandwidth parameter also controls the degree of local smoothing in the trend estimate: larger bandwidths tend to give

smoother, less variable trends, while smaller bandwidths react more nimbly to quickly changing local concentration patterns. To ensure that a reasonable model is fit, GTS allows the user to visually check the bandwidth alternatives and to override, if necessary, the default bandwidth. Some of the mid-level site analysts spent considerable time checking and 'tweaking' the local regression trend models, especially at NOP and Fernald, while others tended to stick with the default bandwidth selections (AFP44).

- *Estimation of Confidence Bands*. Besides the local trend estimate, GTS also computes an approximate 90% confidence band around the trend. This band is useful in its own right as an indication of whether or not the mean concentration level exceeds a regulatory standard at any given point in time. It is also used in temporal optimization during iterative thinning as the numerical demarcation identifying when a reduced-data trend no longer reflects the baseline pattern. This occurs when the reduced-data trend falls substantially outside or beyond the confidence band surrounding the baseline trend. GTS utilizes one of two methods for constructing confidence bands. If the trend type is LWQR, the trend analogue to a standard confidence interval is used which properly accounts for the differential weighting of points in each local neighborhood where a trend estimate is made. If instead the trend type is Theil-Sen, the linear trend is then *bootstrapped* to estimate the confidence band. Currently, GTS does not use Theil-Sen trend cases when executing iterative thinning. At the test sites, since 178 (22%) of 794 non-flat trends with more than 4 observations were classified as Theil-Sen, more complete estimates of the optimal sampling intervals might have been made had these trends also been utilized.

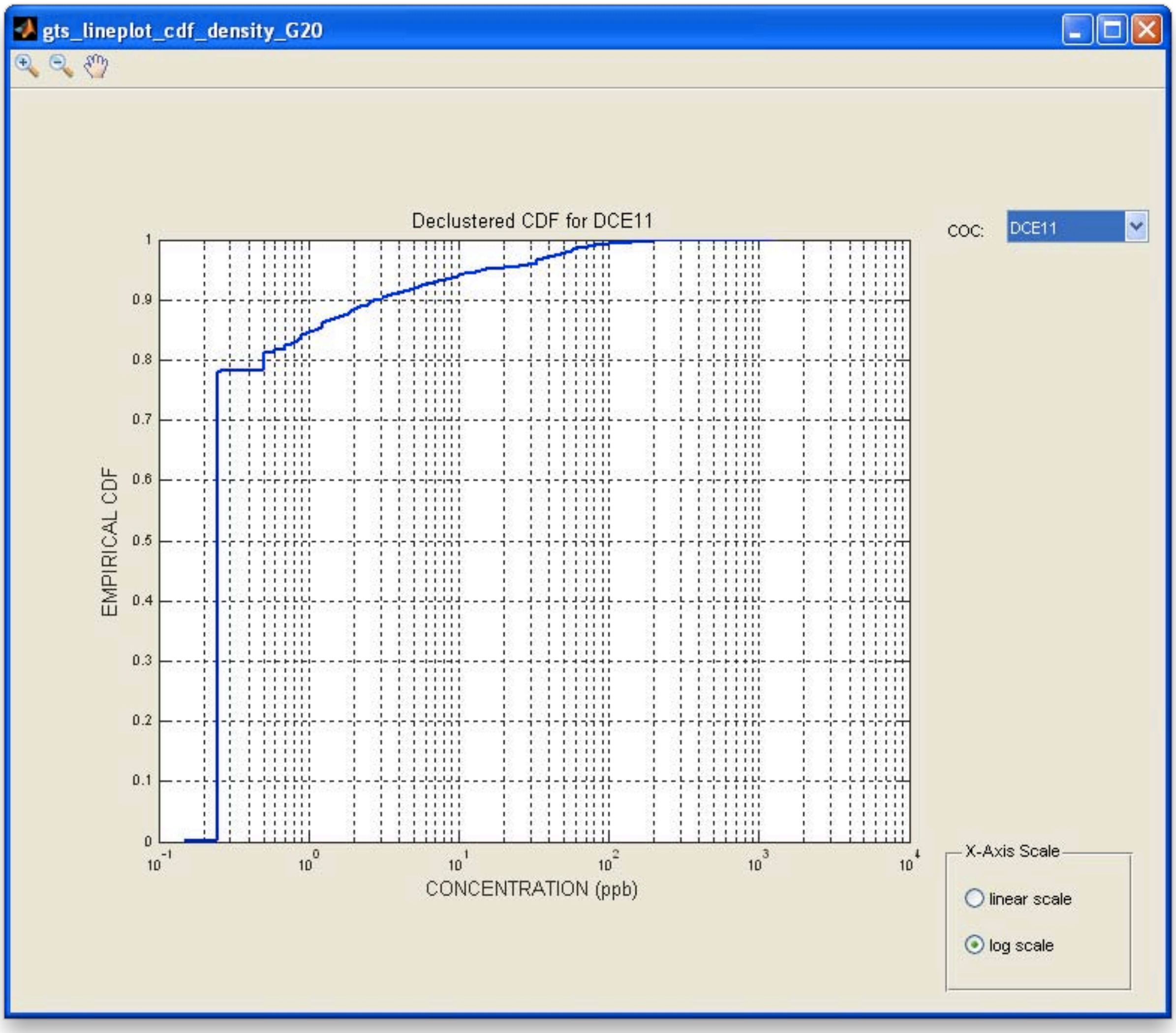
- *Estimation Mesh for Maps*. In building concentration maps across a site area, the area must be discretized and estimates computed at each of a mesh of points. This is done to limit computational time, since interpolation between mesh points is typically much faster than computation of the local regression estimate at a mesh point. GTS currently employs a default mesh of approximately 100 evenly spaced points, but allows the user to override this value by either increasing or decreasing the target number of mesh points (**Figure 5-1**). All of the site analysts opted to retain the default mesh spacing in their analyses. More generally, there are other spatial regression schemes that utilize unequally-spaced meshes, whereby areas with clustered sample points receive tighter mesh coverage, while areas with sparse sample points receive fewer (i.e., looser) mesh points. Such schemes may more effectively map local areas where the plume is highly variable than the current GTS implementation.

**Figure 5-1. Default GTS Estimation Mesh at AFP44**




- *Declustered Cumulative Distribution Function*. To ensure that map estimates are consistent with the range of observed concentrations, GTS computes an empirical cumulative distribution function (CDF) to represent the statistical distribution of recent concentration levels. Each analytic observation sampled during one of the recent time slices is included in the CDF, but weighted according to spatial density (**Figure 5-2**). That is, individual observations in clustered areas receive less weight than observations in more sparsely sampled locations, to better reflect what proportion of the site is represented or 'informed' by those concentration values. The net effect is that the weighting works to 'decluster' the CDF estimate, resulting in a declustered CDF (DCDF). The DCDF is used in turn by the QLR mapping engine to ensure that plume maps in GTS closely reflect the known concentration distribution and thus provide a more accurate baseline.

**Figure 5-2. Example Declustered Cumulative Distribution Function in GTS**

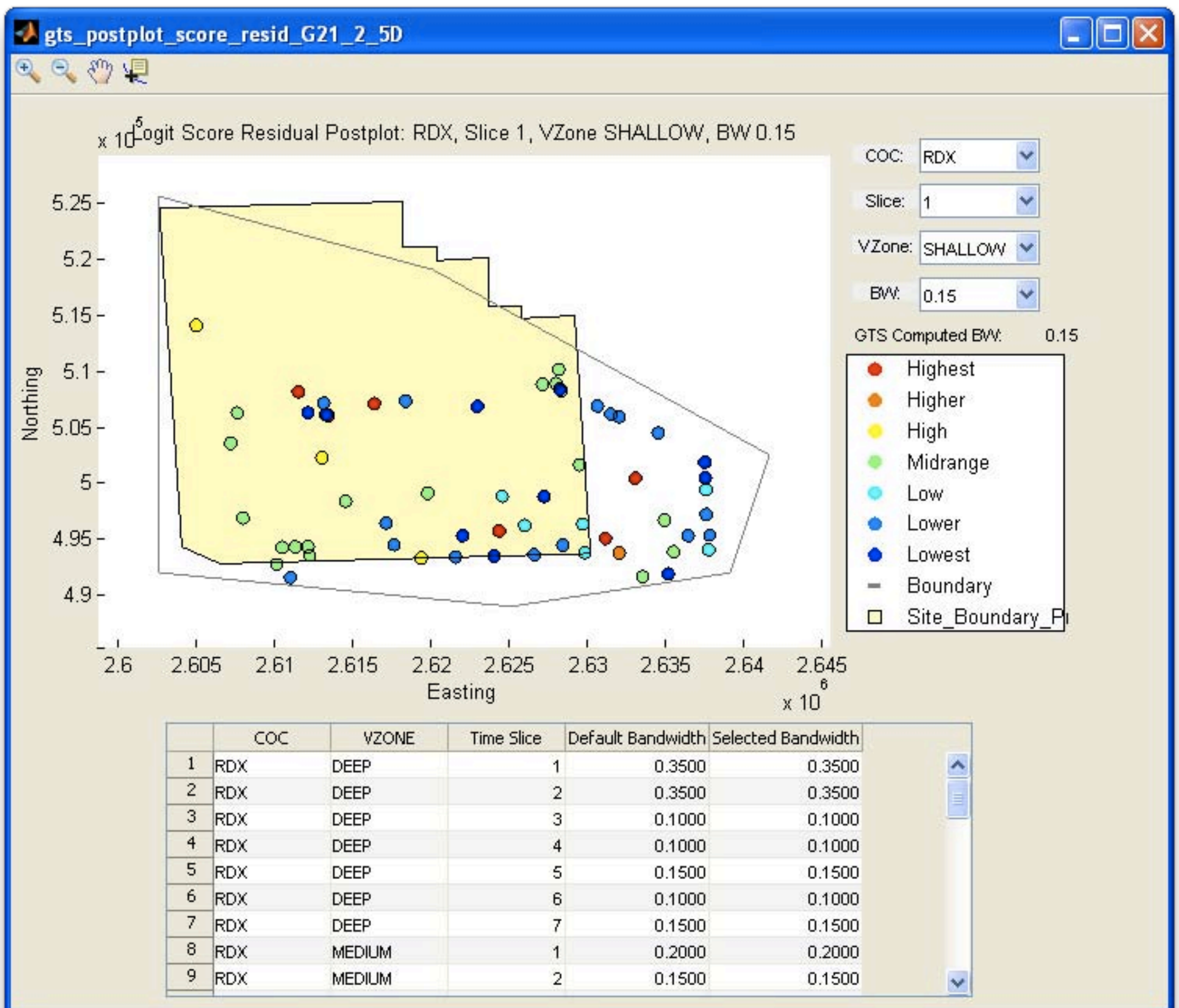



- *Spatial Bandwidth Selection*. Like the local regression trend models, a bandwidth parameter must be chosen for each spatial regression model prior to constructing a base-map. Using the weighted relative residuals described in **Developing an Optimization Strategy**, GTS computes a default bandwidth value for each map based on minimizing a series of diagnostic residual statistics across a range of possible bandwidths. If the default bandwidth does not result in an accurate or reasonable model, the user can override the default with a different bandwidth choice using a diagnostic interface within the program. The interface plots the relative residuals associated with each possible bandwidth as a color-coded post-plot (**Figure 5-3**). Residuals on the 'red' end of the scale represent overestimates, 'blue' residuals represent underestimates, and 'green' residuals are close to the observed target.

  Although easy to use, some GTS testers suggested that the color-coded residuals did not provide enough diagnostic information to clearly identify superior regression models (i.e., base-maps). At least three issues may have contributed to this

impression: 1) The default regularly-spaced mesh may not have allowed for fine-enough interpolation around local hot spots, regardless of choice of bandwidth, leading to ill-fitting base-maps. This could be improved by changing the mesh-building scheme within GTS to put more mesh points in the vicinity of clustered observations. 2) Plots of color-coded residuals are not the only useful diagnostic for selecting good bandwidths. GTS could be improved with additional spatial bandwidth diagnostic tools. 3) Because quantile local regression (QLR) is a *smoother* and not an *interpolator*, when low-valued and high-valued measurements are tightly clustered, the map estimate will necessarily be somewhere between, leading to the presence of both 'red' residuals (overestimates) and 'blue' residuals (underestimates) no matter what choice of bandwidth.

**Figure 5-3. Example Residual Post-Plot**




- *Multiple Time Slices, Multiple Zones*. GTS constructs a concentration base-map of every contaminant for each time slice for which there is sufficient data, as well as for each aquifer zone should multiple zones exist and when a 2.5D analysis has been

selected. Having a base-map for each time slice is, of course, useful for examining changes in plume extent and intensity over time, but the primary reason is to ensure that the optimization results in GTS are *repeatable*. That is, a given well can only be tagged as redundant for a particular contaminant if it is redundant across more than half the time slices. In this sense, GTS is fairly conservative when it comes to identifying spatial redundancy, since the redundancy must exist relative to a majority of the base-maps across the range of time slices.

Different aquifer zones are mapped separately to account for the possibility that groundwater concentration patterns may differ significantly by zone. This could be accomplished by performing multiple runs of the software, each run with a different subset of the data corresponding to a distinct aquifer zone. However, the GTS implementation adds significant ease of use by automatically mapping each aquifer zone separately when a 2.5D analysis is selected. Further, GTS allows the user to merge or delete specific zones for analysis purposes, a task that would be much more cumbersome outside the program. At AFP44, due to the small number of wells in the deepest aquifer zone and the somewhat fuzzy hydrogeologic distinction between aquifers at the site, both the site analyst and the ESTCP project team merged these wells into the Upper Zone Lower Unit (UZLU) to form a combined layer coded by GTS as LZ-UZLU.

**Estimating Costs of the Baseline Monitoring Program**

The final step in baseline characterization was to estimate the costs associated with the monitoring program at each test site prior to optimization. Site personnel and analysts were asked to provide site-specific estimates for laboratory and field sampling costs, as well as costs for factors such as mobilization, equipment, shipping, and labor rates. The current version of GTS includes a separate Excel spreadsheet into which results of an optimization run can be imported, and which guides the user in inputting baseline cost assumptions. The output of this spreadsheet is a realistic cost-benefits tally of the resources likely to be saved by implementing a GTS-optimized sampling program, including the return on investment (ROI).

More detail on the baseline costs estimated at each site is provided in **Section 7.3**. Significant results or observations stemming from this process include:

- *Filled-In Cost Estimates*. Not every test site provided the full range of baseline cost estimates requested by the ESTCP project team. To generate cost savings at these sites, the GTS cost comparison calculator comes pre-loaded with costing assumptions that are fairly typical across the industry. These assumed costs were inputted for the missing values on the cost spreadsheet where necessary, but are noted as estimates in **Section 7.3**.

- *Ease of Use Issues*. None of the independent site analysts completed or returned the GTS cost calculator spreadsheet. This was apparently because 1) the GTS cost calculator is a separate spreadsheet and not part of the main GTS application and therefore requires additional export of data from GTS and subsequent import and manipulation within the cost spreadsheet; 2) some of the site analysts did not have access to the baseline cost assumptions for their site and therefore decided they could not complete the cost spreadsheet; and 3) time constraints. Ideally, the cost

spreadsheet should be part of the main GTS application to encourage, and ease, its use (however, one site analyst opined that it should be kept as a separate application). Once in the spreadsheet, the process to complete a cost analysis is fairly straightforward, but does require some user input and data manipulation. However, since none of the users completed this task, no direct comparison between the site analysts and the ESTCP project team could be made of the cost savings or ROI estimates. Instead, the cost savings reported in this report represent estimates made solely by the ESTCP project team.

## 5.3 TREATABILITY OR LABORATORY STUDY RESULTS

These items do not apply to this ESTCP project.

## 5.4 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

The technology demonstrated in this product is a software product. The design and layout of the software was described in **Section 2.1**, and illustrated on a flowchart in **Figures 2-1, 2-3, 2-5, 2-6, 2-9, 2-10, 2-11,** and **2-16**. Further details are provided in the GTS software users guide, which has been provided as a separate deliverable for this project.

## 5.5 FIELD TESTING

A summary of key results from testing of the GTS v1.0 software is presented in the following sections:

*5.5.1. Schedule for Software Testing*

*5.5.2. Ease of Use, Installation*

*5.5.3. Software Bugs, Software Changes*

*5.5.4. Summary of Temporal Redundancy Evaluations*

*5.5.5. Summary of Spatial Redundancy Evaluations*

*5.5.6. Summary of Network Adequacy Evaluations*

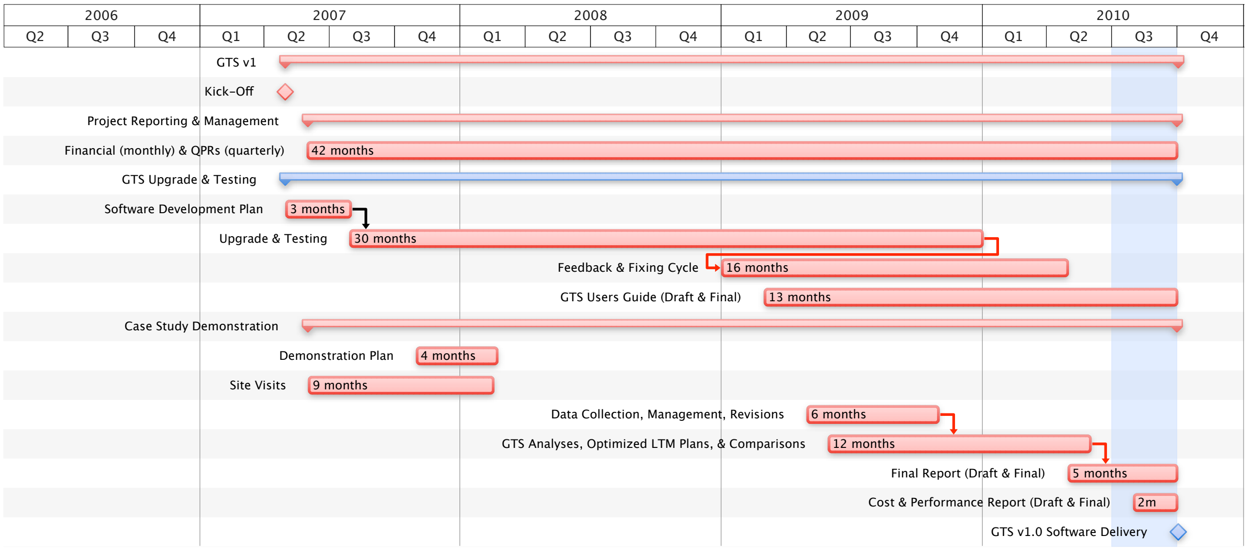
*5.5.7. Summary of Trend and Plume Flagging Results*

*5.5.8. Import/Export Features*

*5.5.9. Computation Time/Level of Effort*

### 5.5.1. Schedule for Software Testing

**Figure 5-4. GTS v1.0 Project and Software Testing Schedule**




### 5.5.2. Ease of Use, Installation

Overall, the GTS software was found to be easy to use by the testers and mid-level site analysts. None of these users was formally trained on the software; questions regarding usage (and other project matters, including software bugs and development) were fielded in weekly conference calls sponsored by the ESTCP project team. Experience with other LTMO software varied among the testers; most had some previous experience running MAROS. Representative comments offered by testers concerning ease of use included the following:

> "This tester rates the general usability of GTS as very good considering it is in beta form. Its modular structure is logical and relatively easy for the minimally experienced geostatistical practitioner to use. Installation and security and administrative rights elements of set up were performed by AFCEE/OSS personnel so the tester cannot adequately evaluate this component of the software." (AFP44)

> "The five major modules coupled with Windows menu and dialog boxes allow an environmental professional with limited statistical training and expertise to navigate successfully through the many spatial and temporal elements of GTS. The graphical user interface (GUI) appears to be highly functional and user friendly. The ability on output graphs to change from linear to logarithmic units and to pan comprises a notable graphical robustness." (AFP44)

> "The software is quite user-friendly. The screens are easy to navigate and read. The screen sequence is logical and appears to be structured to prevent a novice user from by-passing necessary steps. On the other hand, the ability to jump to other steps that have either already been conducted or that can be conducted based on the steps already completed make the program easy to navigate." (NOP)

> "Apart from bugs encountered during the Fernald application, GTS was easily used. The interface made sense and was clear. There are some relatively minor suggestions on improving the user experience described below. Based on my experience, GTS's major benefits are the exploration that can be done with data sets once loaded (outlier searches, data gaps, time series plots, etc.) The major impediments to its use will likely be the following: 1) difficulty in setting up the software and acceptable input files, 2) run times for some of the steps, 3) 'bugs' encountered during application, if my experience turns out to be representative, and 4) interpretation/reasonableness/defensibility of results." (Fernald)

> "The overall ease of use is good, as familiarity with the 5 main modules and their underlying windows comes fairly quickly." (Paducah)

The most consistent problems cited by users during this project related to ease of installation, data import/export (discussed in **Section 5.5.8**), and the level of interpretive detail offered in the users manual. GTS was only certified to run under a (32 bit) Windows XP or equivalent operating system environment. Users who attempted to install GTS under Windows Vista or Windows 7 were mostly successful but occasionally encountered glitches that prevented completion of the installation process. Additionally, several government users had to obtain special permissions and/or assistance from IT personnel in order to circumvent security firewalls. Frequently, the user had to install GTS on their computer as a system administrator in order for GTS to run properly.

Comments were received from some testers regarding the lengthy time required to initially install GTS. Updates to the software install fairly quickly. However, the first go around requires installation of several separate software components, all related to the open source, freeware architecture of GTS. Once these components are installed, they do not have to be installed again except when a particular component has been upgraded. Specific comments related to installation included:

> "Installation should be easy for users with administrative privileges on their computers. For users without administrative privileges, installation can require significant intervention by a network administrator. Installation of multiple builds may cause problems. In my situation, two versions of the supporting program R were present (2.9.1 and 2.10.1). I deleted the older version (required administrator intervention), but then when GTS was opened, it couldn't find R. A deletion and re-install by the administrator was then needed." (Paducah)

> "Set up was a significant issue, primarily because we do not have administrative rights on our machines. In my case I was able, with the assistance of our system administrator, to install on my desktop but was unable to get GTS operational on my laptop (and abandoned trying once it was running on my desktop)." (Fernald)

> "The installation process was somewhat lengthy, but relatively easy. The fact that the software uses a couple of proprietary run-time software means there are several steps to the installation that may be a bit confusing for novice computer users. This should not be an issue for the intended users, though, since they are likely to be quite computer literate. The biggest hurdle for DoD users will likely

> be that the software will require installation by IT staff with administrator rights. This is a problem for most software, although MAROS can be used without an installation, provided the user has Microsoft Access." (NOP)

As to the GTS users guide, testers found it straightforward but concise. Some comments indicated the manual should include more detailed help for interpreting GTS output and results. Representative comments included:

> "The user's guide is well written and concise. There are a number of items and parameters that are not adequately explained, however. In some cases, the ramifications of making certain changes or parameter choices are also not explained. For example, "bandwidth" is not really explained before or at its first use in a way a new user would likely understand (I think my geophysics background helped me). The manual could more fully explain the ramifications of unflagging data points as outliers. Are they or are they not used? It seems they are not used. What happens to the later calculations if you don't change them? What happens if you do? The manual is silent on the genetic algorithm settings for the spatial optimization work. What are the tradeoffs in changing the settings? Other questions for the manual: 1) What are the Logit scores? What are expansion factors?" (NOP)

> "The user's guide provides a good introduction to the GTS algorithm and helpful instructions in preparing input data files and navigating through the five modules and numerous submodules." (AFP44)

> "The User's Guide was, in general, easy to understand and follow. However there were many times when I found the brief description of what GTS was doing inadequate. I would strongly suggest adding appendices that provide technical detail and references, when appropriate, for the various analysis methods and approaches embedded within GTS." (Fernald)

> "The manual has been refined over the last half year and is in good shape. It is light on details, however. A companion guide that documents the math/stats involved in the various steps is recommended." (Paducah)

### 5.5.3. Software Bugs, Software Changes

GTS v1.0 represents a major overhaul and upgrade to the previous beta-version GTS v0.6. The software architecture was completely redesigned and all new software components/tools were utilized to build the new version, including a fundamental switch in the statistical/computational environment from Fortran to R, as well as a brand new interface and data housing structure. As such, a significant number of software bugs, logic flaws, and glitches were encountered during both the early internal testing of GTS, as well as in the external testing by the mid-level site analysts. Due to the project schedule, it was necessary to have most of the site testers begin their analysis prior to the final software release. While this caused some significant frustrations on their part, it had the beneficial side effect of identifying additional GTS bugs and flaws, issues that were addressed during the project. Apart from software design

changes or suggestions that fell outside the scope of original project proposal, the ESTCP project team addressed each reproducible bug and flaw, resulting in the current final GTS v1.0 release. Tester comments related to software glitches included:

> "Bugs and crashes were common in earlier builds, but the only known problem while analyzing with GTS using the 15March2010 version is the map legend issue described above." (Paducah)

> "I encountered a number of problems as I worked through GTS, some of which were resolved by the GTS team, others of which are still outstanding." (Fernald)

> "Given the difficulty in getting IT support for installation of various subsequent builds of GTS, I encountered a number of problems that potentially were related to the version I was using. In some cases it was related to the dataset I was using. I had reported a number of problems to the GTS team and either my mistake was identified or the code was updated. Due to time constraints and early bugs, I was not able to evaluate the Predict module to assess new data. I understand that the software has been used with the Mead dataset through this step by others. One problem I found with the March 2010 version was that I could not go back and reduce the number CoCs once I passed the CoC selection step." (NOP)

> "The software tester encountered numerous bugs and runtime errors while running the GTS 29 Oct and 11 Nov builds, some of which were fatal, causing shutdown of GTS. These problems occurred both in the XP environment as well as in Vista. These runtime errors are described in detail in the next section. The 15 Mar 2010 version was run on Windows XP utilizing the input file used for the 2009 testing. No runtime errors or 'bugs' were encountered." (AFP44)

In addressing either internal or tester-identified issues, several modifications were made to GTS beyond the software development plan. In all, a total of 34 separate alpha or beta builds of GTS v1.0 were generated. Among the more significant changes:

- Modified the SQLite database structure to allow for data filtering and limited editing. Now within GTS, users can specify complex filtering criteria for creating specific subsets of the database with which to analyze. Immediately after data import, users can also edit individual records and/or fields.
- Improved the usefulness of GTS graphics by adding zooming and panning controls to each plot. Also added the ability on time series plots and other 2D line plots to switch between concentration and semi-log scales.
- Improved the utility of post-plots and maps by adding 'tool tips' to allow the user to identify key information about specific well locations directly from the plot using the cursor, including well name, easting and northing coordinates, and relevant summary statistics.
- Improved the default identification and viewing of potential outliers in multiple ways. Early versions of GTS flagged far too many samples as outliers, requiring more work for a user to override non-outliers. The internal GTS logic for identifying both

temporal and spatial outliers was made more ‘conservative’ and accurate. Non-detects were visually identified on outlier plots to better distinguish true outliers from non-outliers. Also, the user interface for examining spatial outliers was re-designed to allow the user to examine all measurements in the local neighborhood of a potential outlier. Finally, only cases with potential outliers are displayed, significantly reducing the number of plots a user must navigate to finalize the outlier list.

- Added the ‘dot ranking chart’ for visually ranking and identifying contaminants most suitable for further optimization.
- Added an interface allowing users to merge and/or delete specific aquifer zones for purposes of analysis without having to manipulate the data outside GTS.
- Vastly improved the ability to save results in GTS. In the current version, users can request that their project be saved at almost any point in the program. Additionally, GTS internally stores the results of lengthy calculations and large batches of graphics so that those results/plots do not have to be recomputed unless other data has specifically been changed. This internal saving dramatically cuts down on run time.
- Changed the spatial mapping engine from multiple indicator local regression (MILR) to quantile local regression (QLR) in order to substantially improve base-map accuracy and also to dramatically speed map computation. In turn, this change speeds the lengthiest step in spatial optimization.
- Improved the method by which spatial residuals are computed and displayed when checking possible spatial bandwidths. Residuals are now computed on a logit-scale, in parallel with how the local regression estimates are generated. Calculation of residuals also now gives equal relative weight to underestimates and overestimates. Improved the internal method for computing default spatial bandwidths.
- Added an option for the user to easily change and visualize the spatial mesh at which map estimates are made.
- Further tested and improved the default parameters used to run the GTSmart spatial redundancy search, including the size of the network subset search space and the error criteria for identifying optimal networks.
- Added the ‘critical index’ to the spatial optimization results to better identify redundant wells and to allow users to perform further graduated ranking of wells within the classifications of ‘redundant’ or ‘essential.’
- Improved the utility of certain post-plots and water elevation maps by distinguishing locations by well type (e.g., monitoring well, extraction well, injection well, piezometer).
- Improved the utility of the trend flagging and plume flagging tools by allowing users to easily override suggested anomalies.

### 5.5.4. Summary of Temporal Redundancy Evaluations

GTS provides two tools to assess temporal redundancy — temporal variograms and iterative thinning. As discussed in **Developing an Optimization Strategy**, iterative thinning has proven to be a more reliable technique at many of the sites (both ESTCP and otherwise) at which GTS has been applied. However, it requires longer data histories at individual wells than temporal variograms and so is not always applicable. At all three test sites, enough historical sampling data was available to run (and compare) both tools. Presented below are the key results from those analyses, as well as a comparison between results obtained by the ESTCP project team versus the independent site analysts.

***Sampling Frequency Optimization Using Temporal Variograms***

Successful use of the temporal variogram requires that the variogram exhibit a distinct and easily recognized pattern, namely a continuous (and smooth) increase in variogram level as the lag time between sampling events increases, followed by a plateau or constant level when the variogram reaches its 'sill.' The sampling lag at which the sill is first achieved is known as the 'range,' and designates the point of zero correlation in concentration levels between pairs of sampling events spaced in time as much or more than the range.

Finding this kind of pattern can be difficult. Variograms with well-established sills usually require that 1) sample pairs exist in sufficient quantity at a variety of different lags, in order to populate a significant range of possible sampling intervals; 2) concentration levels at most wells are reasonably stable (but not constant) over time, so that trends do not overly influence the estimates of intra-pair correlations; 3) not too many wells included in the temporal variogram have non-detect or 'flat' data histories (i.e., all or almost all measurements are non-detect or constant in value). Lack of variation in concentration levels precludes the ability to correlate sampling lags with concentration patterns.

At the ESTCP test sites, temporal variograms were easily computed, but yielded poor to mixed results. **Table 5-3** lists the number of approximate ranges identified by the ESTCP project team for each test site, against the number of temporal variograms computed. Overall, the results did not enable reliable or replicable estimates of optimal sampling intervals. At AFP44, a sill was evident at only 3 of 11 combinations of COC and vertical zone, including no cases for either TCE or 1,4-Dioxane and no cases for the UZUU aquifer zone. On the plus side, both ranges identified in zone LU-UZLU for different COCs were close to 1,200 days or slightly more than a 3 year recommended sampling interval.

The independent site analyst at AFP44 identified ranges for each combination of COC and aquifer zone, unlike the ESTCP project team. Further comparison of the respective results revealed that the independent analyst attempted to identify the range associated with a 'secondary sill,' so termed because it depicts a temporary plateauing of the variogram, followed by a further increase at larger sampling lags. This discrepancy between the AFP44 site analyst and the ESTCP project team underscores three important points:

1) Estimating optimal sampling intervals using temporal variograms is somewhat subjective, since the analyst must visually identify the sill (if it exists) and then 'flag' the approximate range at which the sill begins. Although GTS documents whatever choice the user makes, multiple users may arrive at different estimates using the same data.

2) A ‘secondary sill’ may or may not provide a nearly optimal sampling interval. On the down side, there will still be some correlation between sample pairs with lags longer than the range of the secondary sill, and hence some statistical redundancy. It is also possible that secondary sills reflect underlying spatial trends in the data. On the other hand, a secondary sill usually represents a significant decrease in that correlation, leading to measurements that are often ‘nearly independent’ with respect to sampling lag.

3) Description of the use and interpretation of temporal variograms in the GTS users guide may need to be more extensive. It is possible users may get the impression that they should pick a range regardless, whether or not a clear sill is evident.

Two COCs — RDX and TCE — were analyzed at the NOP site. Of these, only RDX resulted in variograms with identifiable sills, each with a range on the order of 3-4 years, depending on the aquifer. None of the TCE variograms reached a plateau. The independent site analyst at NOP did not find any identifiable sills, either for RDX or TCE. Upon further inspection, it was determined that his results were computed using a version of GTS that incorrectly limited the maximum range of sampling dates displayed by the temporal variogram. Thus, the sills for RDX were not evident on the variograms he examined. The final release version 1.0 of GTS has fixed this issue.

At Fernald, neither the ESTCP project team or the independent site analyst identified a sill for uranium, the only COC. Both analysts found the temporal variogram to be uniformly increasing over the possible range of sampling lags. As the site analyst put it:

> “In the case of the Fernald data set, no sill was apparent (Figure 18), a result consistent with the fact that uranium concentrations have been gradually falling across the site over time. Whenever consistent temporal trends are present, one would not expect variogram sills to be evident.”

**Table 5-3. Summary of Temporal Variogram Results Obtained by ESTCP Team**

| Site | Aquifer Zone | # COCs | # Sills Found | Median Sampling Interval | Range of Sampling Intervals |
|---|---|---|---|---|---|
| **AFP44** | LZ-UZLU | 4 | 2 | 1220 days | 1200–1250 days |
| | UZUU | 4 | 0 | — | — |
| | SGZ | 3 | 1 | 200 days | — |
| **NOP** | DEEP | 2 | 1 | 1500 days | — |
| | MEDIUM | 2 | 1 | 1500 days | — |
| | SHALLOW | 2 | 1 | 1250 days | — |
| **Fernald** | — | 1 | 0 | — | — |

***Sampling Frequency Optimization Using Iterative Thinning***

Iterative thinning is predicated on the notion of trend reconstruction. If a baseline trend can be accurately reconstructed using fewer and, hence, more infrequent measurements, an optimized sampling interval can be obtained by determining what level of sampling is still necessary to do an accurate reconstruction. As a corollary, the ability to generate the same trends should lead to equivalent decisions concerning whether regulatory standards have been exceeded, remedial action is necessary, or what kinds of temporal changes are occurring. Thus, although GTS v1.0 does not directly compute optimized sampling frequencies on the basis of probable regulatory exceedances or the pace and direction of concentration change over time (i.e., slope), such questions can be answered by the GTS approach. Further, unlike other existing LTMO methods for temporal optimization, the combination of using iterative thinning and local regression for trend fitting accounts for two ubiquitous features of groundwater monitoring: non-linear temporal patterns, including complex and/or seasonal trends, and irregularly-spaced sampling events.

In the current implementation, GTS attempts to optimize any contaminant-well pair with at least 8 distinct sampling events and for which the measurement levels vary with time (i.e., not uniformly non-detect or ‘flat’). Many sites, including the ESTCP test sites, have such data histories. However, the number of eligible contaminant-well pairs can vary significantly, usually by contaminant, depending on general contaminant levels and sampling schedules (e.g., COCs may be sampled on differential schedules leading to different accumulated data histories). **Table 5-4** lists the number of contaminant-well pairs analyzed by iterative thinning at each site, along with the basic results generated by the ESTCP project team. Important observations from this table include:

- At AFP44, 1,4-Dioxane had not been sampled frequently enough to enable iterative thinning at contaminant-well pairs involving this COC. As such, the optimization results at this site are based on 1,1-DCE, TCE, and chromium.
- At AFP44, many wells were still being sampled quarterly (1Q) at the time of the demonstration, so much so that the median baseline sampling frequency was quarterly in each aquifer zone except for SGZ, where the baseline frequency was semi-annual. Iterative thinning suggested that most trends could be adequately reconstructed using an annual sampling effort instead, an overall 75% reduction in the current schedule.
- At NOP, relatively few contaminant-well pairs were eligible for iterative thinning. Although data existed for 462 contaminant-well pairs, 295 (64%) of these were always non-detect, 57 (12%) had an insufficient number of sampling events to fit any trend, and 53 (11%) had only enough data to fit a Theil-Sen non-parametric linear trend (but not the 8 events required to do iterative thinning). That left 57 (12%) eligible pairs. On one hand, the small number of pairs might seem to provide a weak justification for recommending a change in sampling frequency. However, the vast majority of pairs that were always non-detect could conceivably be sampled at any frequency and still give the same result. So the key to temporal optimization are the contaminant-well pairs with variable trends, even if fewer of those exist.
- At NOP, the majority of wells in each aquifer zone were sampled semi-annually (2Q) at time of the demonstration. Iterative thinning suggested that adequate trend reconstruction could be done based on annual (4Q) sampling in two of the three aquifer zones, and every three quarters (3Q) in the remaining SHALLOW zone. Overall, the GTS analysis recommended roughly half the level of sampling effort as was currently being conducted.
- At Fernald, since the only COC analyzed was uranium, there was a 1-1 correspondence between the total number of wells and the total possible number of contaminant-well pairs. However, at 209 (45%) of the 467 locations, the data were insufficient to fit any trend, primarily because most of this group of ‘wells’ was in fact DPT-type ‘geoprobes,’ and thus temporary sampling locations rather than permanent wells. Another 13 (3%) locations were always non-detect for uranium, while 28 (6%) only had enough distinct sampling events to be fit via a non-parametric linear trend (Theil-Sen). The remaining 217 (46%) were analyzed with iterative thinning.
- At Fernald, a large majority of the wells with sufficient data were being sampled, on average, quarterly (1Q) at the time of the demonstration. The GTS analysis recommended an overall reduction in sampling frequency to once every three quarters (3Q), based on the median optimal sampling interval, a reduction in sampling effort of roughly 67%. However, at this site (and more so than the other two) there was significant variation in the well-by-well iterative thinning results (see **Figure 5-5**). In fact, 100 (46%) of the optimal intervals were either every two quarters (2Q) or quarterly (1Q). Closer examination of the results showed that 30 of these wells were being sampled *weekly* at the time of the demonstration. So a reduction in sampling frequency to quarterly at these locations was fairly substantial.

**Table 5-4. Summary of Iterative Thinning Results Obtained by ESTCP Team**

| Site | Aquifer Zone | Total # Wells | Eligible Pairs | Base Median Sampling Interval | Optimal Median Sampling Interval |
|---|---|---|---|---|---|
| **AFP44** | All | 208 | 342 | 1Q | 4Q |
| | LZ-UZLU | 69 | 133 | 1Q | 4Q |
| | UZUU | 85 | 136 | 1Q | 4Q |
| | SGZ | 54 | 73 | 2Q | 5Q |
| **NOP** | All | 250 | 57 | 2Q | 4Q |
| | DEEP | 58 | 16 | 2Q | 4Q |
| | MEDIUM | 96 | 21 | 2Q | 4Q |
| | SHALLOW | 96 | 20 | 2Q | 3Q |
| **Fernald** | — | 467 | 217 | 1Q | 3Q |

***Iterative Thinning Comparison Between ESTCP Project Team and Site Analysts***

A comparison was also performed between iterative thinning results generated by the ESTCP project team versus those submitted by the independent site analysts. Key results of this comparison are shown in **Table 5-5** and **Figure 5-5**. In general, both sets of analysts at AFP44 and NOP computed fairly similar results using GTS on the same data, underscoring the reliability of GTS as a computational tool. More significant differences were found at Fernald, as discussed below. Important observations include:

- The recommended site-wide optimal sampling intervals were identical for both the 'expert' and independent site analyses at AFP44 and NOP. The only differences occurred in aquifer zone-specific recommendations: once at AFP44 and once at NOP. In each case, the median optimal intervals differed by one quarter in length.
- At Fernald, the data sets imported into GTS differed significantly between the ESTCP project team and independent site analyst (see **Developing an Optimization Strategy**). In particular, the Fernald analyst eliminated most of the 'geoprobe' locations and any wells outside a fairly central and smaller area than that delineated by the site boundary utilized by the ESTCP project team. As a consequence, the Fernald analyst employed a total of 172 well locations in his analysis, contrasted with

the 467 locations used by the ESTCP project team. Due to the difference in input data, it is somewhat difficult to make a direct comparison in results. Even the baseline frequencies differ: in the commonly-supplied data set, 164 (76%) of 217 eligible wells had baseline sampling frequencies that were either weekly or quarterly (1Q). In the data set used by the Fernald analyst, 93 (77%) of 121 eligible wells had semi-annual (2Q) baseline frequencies, while only 22 (18%) were quarterly or weekly.

- Despite these obvious differences in the two Fernald analyses, both teams computed a *lengthening* of the optimal sampling interval by two quarters on average, and a typical reduction in sampling effort of at least 50%.
- At Fernald, the site analyst performed additional follow-up analyses of the iterative thinning results. He found that:

  > "There was a correlation noted between base sampling frequency and the GTS-recommended frequency. The longer the base sampling frequency, the longer was the GTS-recommended sampling frequency. Ideally one would want the 'optimal' sampling frequency to be independent of the original sampling frequency.'

  Actually, the correlation is entirely consistent with the fundamental assumption that GTS is appropriate only for sites with too much sampling data, rather than too little. Iterative thinning always attempts to *remove* data prior to trend reconstruction. This guarantees that the optimal sampling interval will never be shorter than the baseline interval; hence, the longer the baseline interval, the longer the optimal interval.

- The Fernald site analyst also noted that:

  > "there was no correlation between the GTS-recommended sampling frequency and the average concentration for a well. One might expect that wells that are significantly and consistently elevated above a cleanup guidelines, or significantly and consistently below, might be of lesser interest from a sampling frequency perspective than wells that have concentrations around the action level."

  This finding underscores how GTS is primarily concerned with trend reconstruction, regardless of concentration level. Other strategies for temporal optimization clearly exist, but it is also true that if an historical trend can be accurately reconstructed, the same regulatory or remedial decisions — one way or the other — will likewise tend to be made.

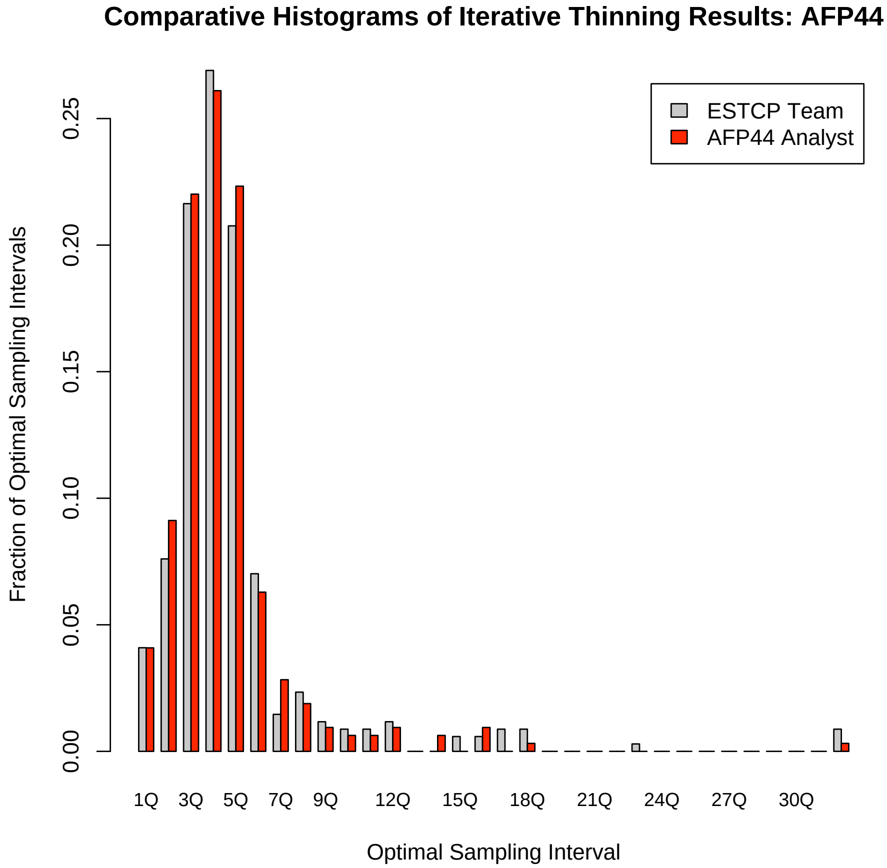
- The comparative histograms in **Figure 5-5** for AFP44 of the individual contaminant-well pair-specific optimal sampling intervals are very similar in shape and magnitude. A Kolmogorov-Smirnov comparative test of the two distributions found a highly non-significant p-value of 0.994, underscoring the visual similarity. Greater differences are seen in the comparative histograms for NOP, though the two distributions still exhibit similar patterns, enough so that the Kolmogorov-Smirnov test gave a non-significant p-value of 0.526.

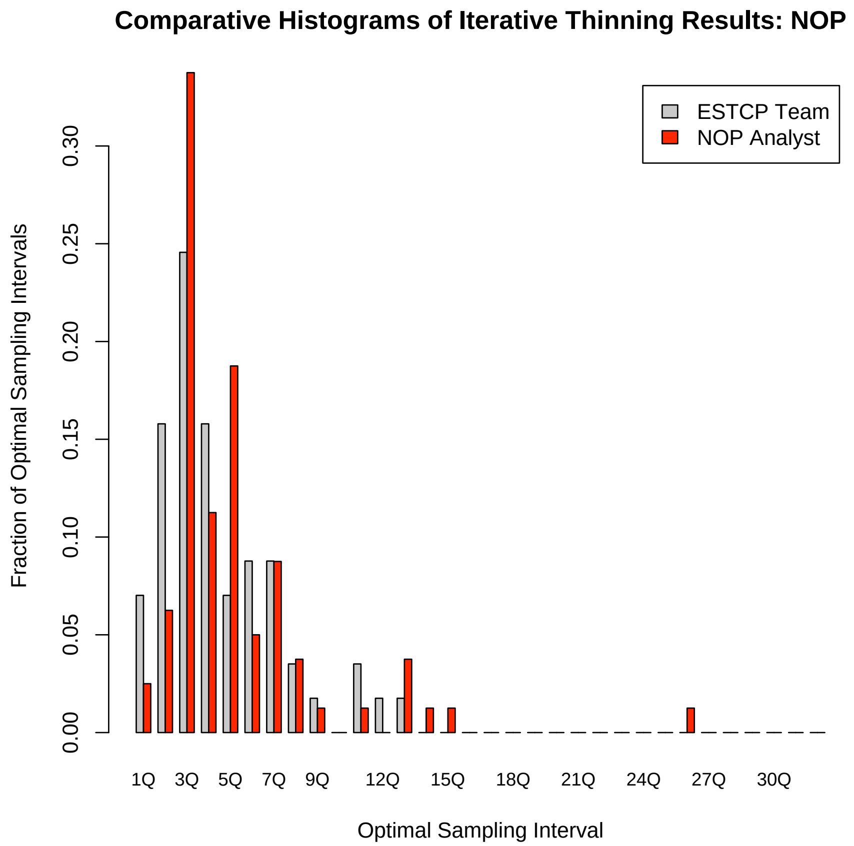
- The comparative histograms in **Figure 5-5** for Fernald of the individual contaminant-well pair-specific optimal sampling intervals are fairly distinct, apparently due to the differing data sets that were analyzed. The Kolmogorov-Smirnov comparative test of the two distributions is highly significant ($p < 0.0001$), confirming the visual differences. It is also clear that more of the optimal sampling intervals computed by the Fernald analyst are longer than those calculated by the ESTCP project team, much of this due to the longer average baseline intervals within the data set utilized in the independent analysis.
- When exactly the same data is analyzed (unlike the Fernald case), it can lead to differing individual optimal sampling intervals for at least four reasons: 1) choice of outliers — the user is responsible for selecting a list of outliers to exclude from analysis. The choice here may impact which trends have sufficient data for iterative thinning. 2) choice of COCs — the user must select which COCs to analyze. At NOP, the site analyst included in his final run Methylene Chloride (MC) and TNT along with RDX and TCE as contaminants to be optimized. The ESTCP project team only included RDX and TCE, since the other contaminants were ranked as having much poorer optimization potential. During iterative thinning, this difference in COC choice led the NOP analyst to optimize 80 contaminant-well pairs, as opposed to the 57 analyzed by the ESTCP project team. 3) choice of temporal bandwidth — the user must review and finalize a temporal bandwidth for each contaminant-well pair that will be subjected to iterative thinning. Different bandwidths impact the smoothness of the trend and sometimes how much data is needed to reconstruct it accurately. 4) thinning process — iterative thinning involves drawing subsets at random from the data history of a given contaminant-well pair. Although this process is repeated many times and the results averaged, the same pair might occasionally yield different results on different runs through the iterative thinning routine.

**Table 5-5. Comparison of Iterative Thinning Results**

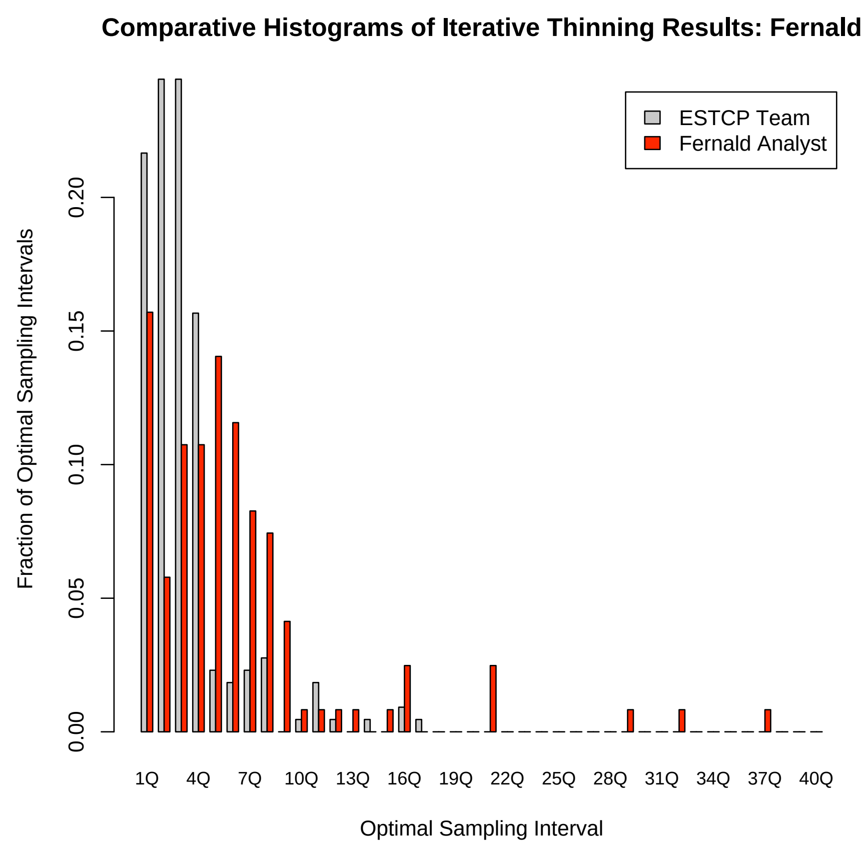
| Site | Aquifer Zone | ESTCP project team Base Interval | Independent Site Analyst Base Interval | ESTCP project team Optimal Interval | Independent Site Analyst Optimal Interval |
|---|---|---|---|---|---|
| **AFP44** | All | 1Q | 1Q | 4Q | 4Q |
| | LZ-UZLU | 1Q | 1Q | 4Q | 4Q |
| | UZUU | 1Q | 1Q | 4Q | 4Q |
| | SGZ | 2Q | 2Q | 5Q | 4Q |
| **NOP** | All | 2Q | 2Q | 4Q | 4Q |
| | DEEP | 2Q | 2Q | 4Q | 5Q |
| | MEDIUM | 2Q | 2Q | 4Q | 4Q |
| | SHALLOW | 2Q | 2Q | 3Q | 3Q |
| **Fernald** | — | 1Q | 2Q | 3Q | 4Q |

**Figure 5-5. Comparative Histograms of Individual Optimal Sampling Intervals**





Comparative Histograms of Iterative Thinning Results: NOP
ESTCP Team
NOP Analyst
Fraction of Optimal Sampling Intervals
0.00
0.05
0.10
0.15
0.20
0.25
0.30
1Q 3Q 5Q 7Q 9Q 12Q 15Q 18Q 21Q 24Q 27Q 30Q
Optimal Sampling Interval

Comparative Histograms of Iterative Thinning Results: Fernald
ESTCP Team
Fernald Analyst
Fraction of Optimal Sampling Intervals
0.00
0.05
0.10
0.15
0.20
1Q 4Q 7Q 10Q 13Q 16Q 19Q 22Q 25Q 28Q 31Q 34Q 37Q 40Q
Optimal Sampling Interval

### 5.5.5. Summary of Spatial Redundancy Evaluations

GTS v1.0 evaluates spatial redundancy using the same general philosophy as iterative thinning, but applied to maps instead of trends. A base-map is created utilizing all applicable data, subsets of the data are randomly generated, and each subset is tested to determine how accurately the base-map is reconstructed. Then, based on the degree of estimation error, a subset is deemed as 'optimal' if it is the smallest network configuration that adequately recreates the base-map.

Since the number of possible well subsets is prohibitively large for all but fairly small sites, a search procedure is required to intelligently winnow through possible subsets. One option in this regard is a genetic search algorithm, such as employed by the Summit Tools LTMO software. The current version of GTS utilizes a quasi-genetic search strategy known as *GTSmart*. Like a true genetic algorithm, each possible network configuration (i.e., subset of well locations) is coded as a binary 'string' and a large initial population of such strings is generated for testing against the base-map. On the other hand, the strings in GTS are not 'mated' or 'mutated' to form new strings as in a formal genetic algorithm. Rather, since QLR-based maps are computationally 'expensive,' GTS only picks an optimal subset from the initial population of strings.

To ensure that the initial population of strings reasonably 'covers' the search space of possible subsets, the search strings are formed 'smartly:'

- The practical range of possible fractions of total number of wells included in a given subset (i.e., 0.05 to 0.96) is evenly divided into 13 'bins' (e.g., 0.05–0.12, 0.12–0.19, etc.). Then an equal number of unique strings are targeted for selection from each bin. That is, a randomly-generated string from a given bin is only included in the initial population if the fraction of 'kept' wells falls within the range defined for that bin. The net effect is to force the initial population of strings to include a wide variety of possible well configurations, from subsets with only a few wells to those with nearly the full complement.

- Strings are also 'screened' according to average interwell distance between pairs of locations. Based on a fixed percentile of the distribution of interwell distances in the full well configuration, strings are only accepted for testing if the average interwell distance in the string is at least as great as this percentile distance. This ensures that subsets in the initial population spatially 'cover' the site area in a similar manner as the full well configuration, and strongly discourages strings that are tightly clustered in only a portion of the site.

- Protected wells — wells designated as ineligible for optimization — are always included in every string within the initial population.

Once the population of strings is formed, quantile local regression (QLR) is used to form a map for each string — based on data from wells included in that subset — and tested against the base-map for absolute statistical bias. The optimal string is that subset which includes the least number of well locations, yet the map based on that string differs from the base-map by no more than the bias constraints described in **Section 2.1 (Optimize Module)**. The same process is repeated for each COC, time slice, and aquifer zone (if a 2.5D analysis has been selected). Then the optimal strings are compared across time slices and COCs for each vertical zone (if any). A

given location is tagged as ‘redundant’ if it is ‘missing’ from the optimal strings at more than half the COC-time slice pairs. All other locations are tagged as ‘critical.’

In the ESTCP demonstration, GTSmart was applied to each test site by the ESTCP project team in the configurations listed in **Table 5-6**. In addition, as discussed in **Section 5.1**, two versions of the AFP44 data package were prepared, given the uncertain aquifer zone designations for certain wells. This impacted the number of wells in the LZ-UZLU and UZUU zones, but was otherwise the only difference between the two data sets. **Table 5-7** summarizes the level of spatial redundancy found at each site, stratified by aquifer zone.

**Table 5-6. Data Configurations Used in Spatial Optimization by ESTCP Team**

| Site | Analysis Type | COCs | Aquifer Zones | # Time Slices |
|---|---|---|---|---|
| **AFP44** | 2.5D | TCE, Chromium, 1,4-Dioxane, 1,1-DCE | LZ-UZLU, UZUU, SGZ | 6 |
| **NOP** | 2.5D | TCE, RDX | DEEP, MEDIUM, SHALLOW | 7 |
| **Fernald** | 2D | Uranium | Single Layer | 4 |

**Table 5-7. Summary of Spatial Redundancy Computed by ESTCP Team**

| Site | Aquifer Zone | Total # Unprotected Wells | # Redundant Wells | Percentage Redundant |
|---|---|---|---|---|
| **AFP44 – Vers 1** | LZ-UZLU | 36 | 4 | 11% |
| | UZUU | 117 | 21 | 18% |
| | SGZ | 53 | 25 | 47% |
| | All | 206 | 50 | 24% |
| **AFP44 – Vers 2** | LZ-UZLU | 68 | 11 | 16% |
| | UZUU | 85 | 22 | 26% |
| | SGZ | 53 | 20 | 38% |
| | All | 206 | 53 | 26% |
| **NOP** | DEEP | 35 | 16 | 46% |
| | MEDIUM | 71 | 9 | 13% |
| | SHALLOW | 71 | 3 | 4% |
| | All | 177 | 28 | 16% |
| **Fernald** | — | 376 | 149 | 40% |

**Table 5-8. Comparison of Spatial Redundancy Results**

| Site | Aquifer Zone | Total # Eligible Wells | # Redundant Wells (% Redundant) — ESTCP project team | # Redundant Wells (% Redundant) — Independent Site Analyst |
|---|---|---|---|---|
| **AFP44 – Vers 1** | LZ-UZLU | 36 | 4 (11%) | 6 (17%) |
| | UZUU | 117 | 21 (18%) | 24 (21%) |
| | SGZ | 53 | 25 (47%) | 27 (51%) |
| | All | 206 | 50 (24%) | 57 (28%) |
| **NOP** | DEEP | 35 | 16 (46%) | 25 (71%) |
| | MEDIUM | 71 | 9 (13%) | 39 (55%) |
| | SHALLOW | 71 | 3 (4%) | 15 (21%) |
| | All | 177 | 28 (16%) | 79 (45%) |
| **Fernald** | — | 376 | 149 (40%) | 31 of 153 (20%)*<br>84 of 153 (55%)** |

* As summarized in written report submitted by Fernald site analyst

** As tabulated from GTS spatial optimization report submitted by Fernald site analyst

Important observations and results stemming from the spatial redundancy analysis include the following for each site, where comparisons of results with the independent site analysts are also noted:

***Spatial Optimization at AFP44 Including Comparison With Site Analyst***

- Despite the reclassification of 32 wells from zone UZUU to LZ-UZLU in creating version 2 of the database, roughly a quarter of the wells were found to be redundant using both versions. Similarly, both runs of the analysis found greater levels of redundancy in the uppermost aquifer zones and less in the deepest layers. This suggests a rough level of repeatability in the GTS results. Note, however, that there was greater redundancy found among the SGZ wells in the first run (Version 1) than in the second run (Version 2), even though the same wells and data were available to both runs for this aquifer zone. Despite the 'smart search' performed by GTSmart, the

possible well subsets considered in any given optimization differ from run to run, leading to some variation in the results.

- The two versions of the database were compared to determine a) how many wells were found to be redundant in both optimization runs (i.e., overlap), and b) how 'close' spatially were the two sets of redundant wells. Ostensibly, if clusters of wells are providing redundant statistical information (in terms of informing plume maps) and the concentration patterns are spatially continuous, there may not be a single 'right' well to 'delete' within a given cluster. Rather, more than one choice of redundant well might be possible and still allow accurate reconstruction of the base-map. Under this supposition, if there exist specific areas of the site with redundant well clusters, different optimization runs on the same data ought to yield sets of redundant wells that either substantially overlap and/or are reasonably similar in spatial placement.

- To test this idea more concretely, the redundant wells (n = 50) from version 1 of the database were compared against the redundant wells from version 2 (n = 53). It was determined that 25 locations were the same in both runs. Further, based on extensive Monte Carlo sampling (N = 10,000 runs) of same-sized sets of locations from the full list of 206 unprotected (i.e., eligible) AFP44 wells, it was found that a randomly-picked set of 53 wells would only average about 13 locations in common with the version 1 redundant wells. Indeed, none of the Monte Carlo well sets had more than 24 locations in common, indicating that an overlap of 25 wells was highly statistically significant and that the separate GTS runs were consistently locating similar sets of redundant wells.

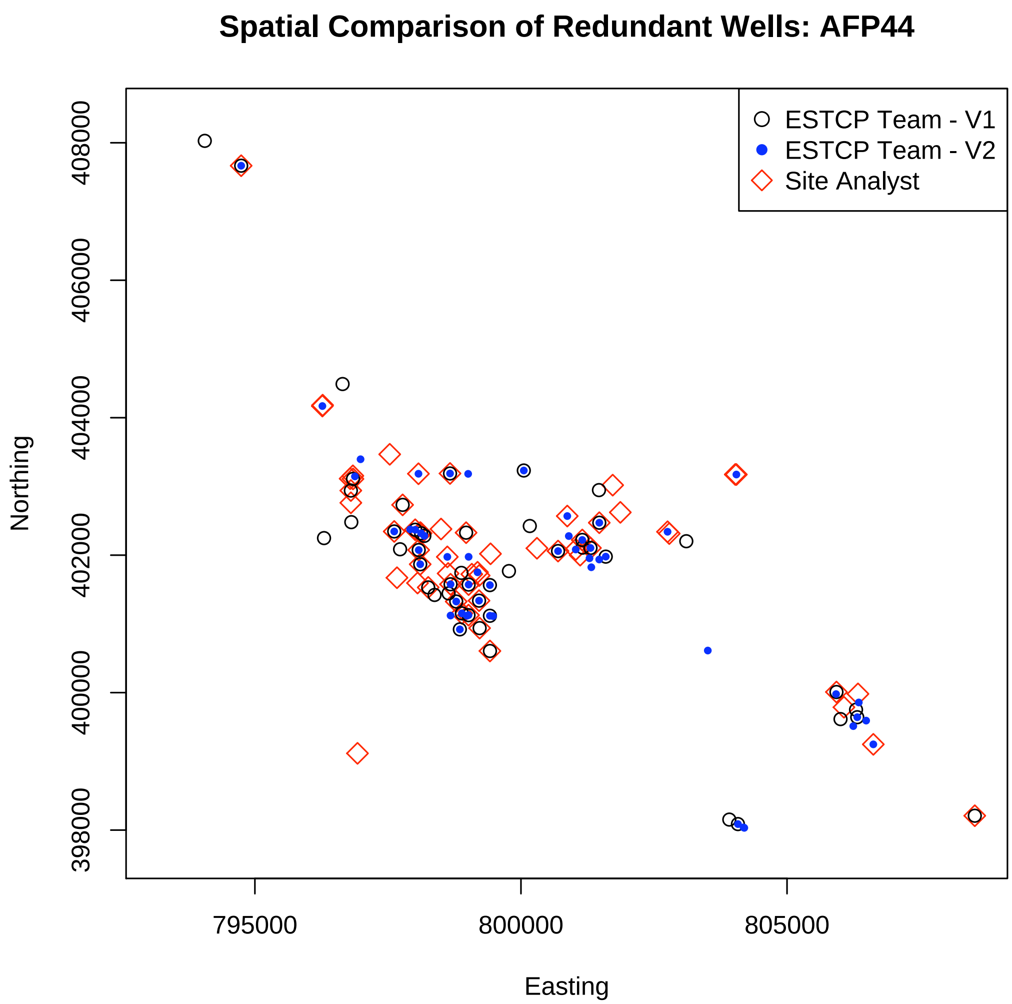
- The ESTCP project team also examined the spatial placement of both sets of redundant wells (see **Figure 5-6**). The two sets of locations are visually similar. To quantify the proximity, the average distance was computed between each well in the second set and its nearest neighbor in the first set. This mean distance was 170 feet, compared to a typical mean interwell distance of 521 feet between nearest pairs in a randomly-selected test set of locations matched against the AFP44 version 1 redundant well set. Again, *none* of the Monte Carlo-generated well sets had a mean interwell pair distance less than 194 feet, suggesting that GTS was identifying redundant wells from the same areas of the site in both optimization runs.

- The site analyst optimized Version 1 of the database, as per the test design. As documented in **Table 5-8**, the site analyst identified 2-3 more wells as redundant per aquifer zone than the ESTCP project team, for an overall redundancy result of 28% (vs. 24% for the ESTCP project team). The results seem quite similar, especially when viewed as a pattern across aquifer zones. Like the ESTCP project team, greater redundancy was identified at shallower depths than in the deeper aquifer zones, mostly attributable to the far greater density and clustering of wells in the SGZ layer.

- To compare the similarity between the results of the independent site analyst and those of the ESTCP project team, the same Monte Carlo testing was employed to measure the overlap and spatial proximity of the two sets of redundant wells. The site analyst matched 26 locations found by the ESTCP project team (out of 50 target redundant wells), and had a mean pairwise interwell distance of 243 feet. Thus, both

the number of redundant locations in common and the mean interwell distance were slightly greater than the AFP44 Version 2 optimization run, but quite unlike the distribution of common locations or mean interwell distances exhibited by a randomly chosen set of wells. None of the Monte Carlo-generated well sets (n = 57 per set) had more than 25 wells in common with Version 1 of the ESTCP project team optimization run, and the typical number in common was only 14. Likewise, all of the random well sets had a mean interwell pair distance of at least 245 feet, with a mean value of 530 feet.

**Figure 5-6. Spatial Comparison of Redundant Wells — AFP44**



***Spatial Optimization at NOP Including Comparison With Site Analyst***

- Only 16% of the unprotected wells were deemed redundant in the ESTCP project team analysis, including only 4% of the shallowest locations. However, the results varied substantially by aquifer zone, underscoring the importance of a 2.5D analysis at this site. The DEEP layer exhibited the smallest range of variation in concentration levels and much greater redundancy as a consequence (46%).
- By contrast, the independent Site analyst found much higher levels of redundancy than the ESTCP project team (45% vs. 16%), including greater redundancy within each aquifer zone (see **Table 5-8**). Upon further investigation, the differences are probably attributable to two factors: a) outlier removal and b) choice of COCs, discussed in more detail below.
  - Outlier removal — Given the large fractions of non-detects in many of the analytes at the NOP site, and the variation in reporting limits, GTS identified a particularly large number of apparently spurious outliers at NOP. Most of these were 'weeded out' (i.e., overridden) by the ESTCP project team prior to spatial optimization. The same was done by the NOP site analyst in his initial run through the data. However, when he re-ran the analysis on a newer version of GTS, the site analyst utilized the default set of outliers, resulting in the removal of a larger number of data points compared to the ESTCP project team. This had the impact of lessening the degree of observed variation at the site, particularly among COCs that already had very high non-detect levels (see below).
  - Choice of COCs — Given the very high non-detect levels associated with both MC (86%) and TNT (96%) at NOP, the ESTCP project team chose not to optimize on these contaminants (or three others that were very similar) due to their poor optimization potential. Instead, only RDX and TCE were optimized, consistent with the persistent presence and extent of these chemicals at the site, and also consistent with a comment from the NOP representative that remedial decisions at the site were made on the basis of those two COCs. By contrast, in the optimization run submitted to the ESTCP project team, the NOP Site analyst also optimized on MC and TNT in addition to RDX and TCE.

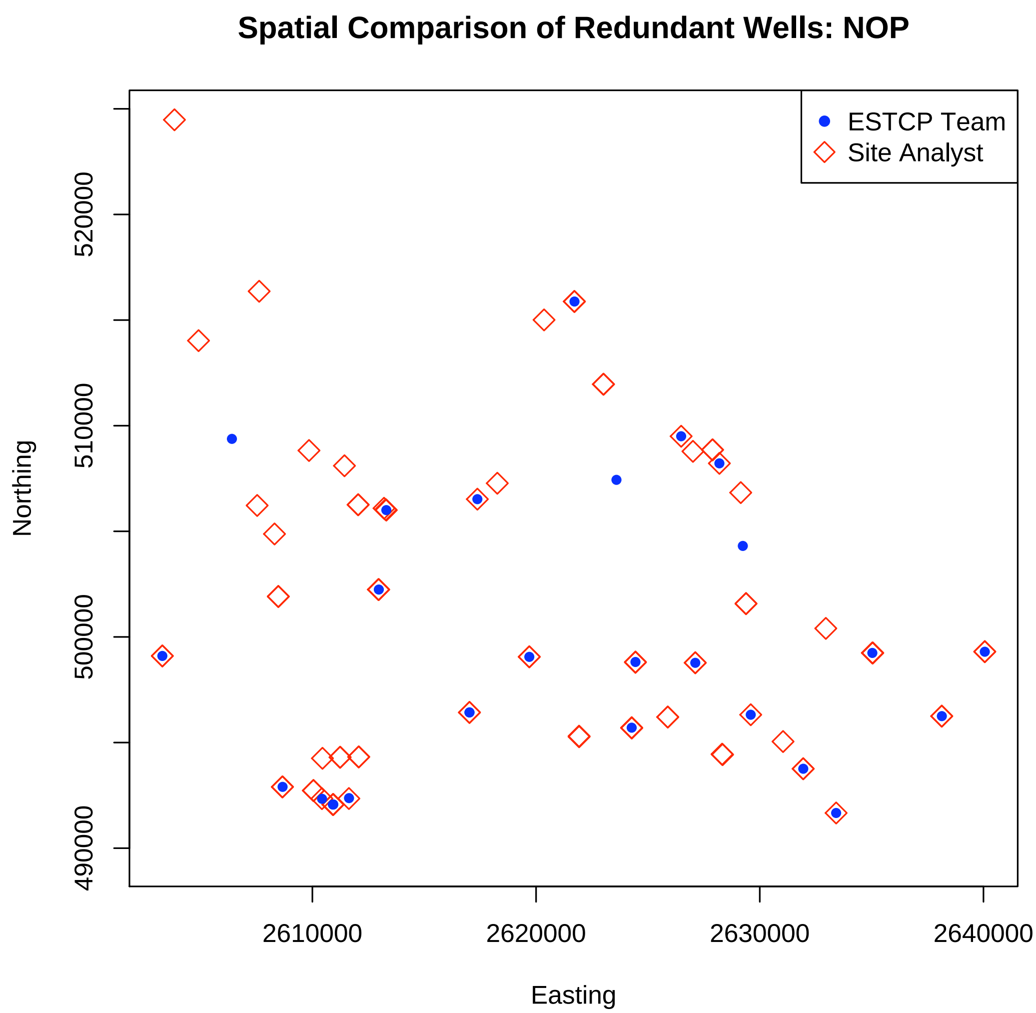
    Given the much smaller degree of variation in concentration levels for both MC and TNT (also exacerbated in the larger number of 'outliers' removed by the independent site analyst), it was easier for GTS to remove additional wells and still accurately reconstruct a less variable base-map. (At the extreme end, one could remove all but one well from a map consisting entirely of non-detects with a constant reporting limit.) Thus, the optimal network for monitoring MC and TNT was much smaller than the optimal network for monitoring RDX and TCE.

    The net effect of this choice was therefore to increase the probability that a given well would be flagged as 'redundant.' Currently in GTS, each COC-time slice pair is given equal 'weight' when forming the critical index used to distinguish essential from redundant wells. Any well tagged as 'essential' in less than half the COC-time slice pairs is then flagged as 'redundant' overall. By including MC and TNT in his analysis, the independent site analyst gave

roughly half the spatial optimization 'weight' to these COCs, at the expense of the two main contaminant drivers.

- As an aside, the independent site analyst generated two spatial optimization runs, one on an earlier beta version of GTS (not submitted to the ESTCP project team) and one on a more stable later release. In his earlier run, the site analyst only utilized RDX and TCE as contaminant drivers and commented that he found very similar levels of redundancy compared to the ESTCP project team (~20%). However, the ESTCP project team did not have access to the earlier run in order to make a detailed comparison of the results. The site analyst also noted that he apparently included MC and TNT in his second optimization run by mistake and attempted to 'deselect' these COCs without success (a software glitch in GTS).
- To further parse out similarities/differences between the analyses of the ESTCP project team and site analyst, a post-plot of the two sets of redundant wells is presented in **Figure 5-7**. Although there are clearly more redundant wells identified by the site analyst, for reasons explained above, it is also evident that almost all the ESTCP project team redundant locations were also matched by the site analyst.
- To quantify the degree of overlap, the redundant wells (n = 28) from the ESTCP project team analysis were compared against the redundant wells from the Site analyst (n = 79). 23 locations were the same in both optimization runs. Further, based on extensive Monte Carlo sampling of same-sized sets of locations from the full list of 173 eligible NOP wells, it was found that a randomly-picked set of 79 wells would only average about 12 locations in common with the ESTCP project team redundant wells. Indeed, none of the Monte Carlo well sets had more than 23 locations in common, indicating that an overlap of 23 wells was highly statistically significant and that the independent GTS analyses were consistently locating many of the same redundant wells.
- The ESTCP project team also quantified the spatial placement of both sets of redundant wells. The mean interwell distance between nearest neighbor pairs from the two sets was 1350 feet, compared to a typical mean interwell distance of 1880 feet between nearest pairs in a randomly-selected test set of locations matched against the ESTCP project team redundant well set. Further, fewer than 0.5% of the Monte Carlo-generated well sets had a mean interwell pair distance less than 1350 feet, suggesting that GTS was identifying redundant wells generally from the same areas of the site in both optimization runs, despite the difference in total numbers of redundant wells.

**Figure 5-7. Spatial Comparison of Redundant Wells — NOP**




***Spatial Optimization at Fernald Including Comparison With Site Analyst***

- At Fernald, when the results were stratified by well type, 49% of the DPT locations were found to be redundant, as opposed to 34% of the permanent wells (i.e., monitoring wells, extraction/injection wells). Optimization of the DPT locations reflected the following assumption: any location deemed redundant need not be mobilized for a direct push sample in the future, while those deemed critical should be resampled periodically within the same local subarea.
- In his sensitivity analysis comparing the impact of choice of bandwidth on the spatial optimization results at Fernald, the independent site analyst found significant differences depending on the bandwidths selected. As the analyst noted:

> "With the smallest spatial bandwidth selected, GTS identified 35 wells as redundant, not a significantly different number than for the base case when

GTS self-selected well-specific bandwidths. However of these 35, only five were in common with the 31 wells GTS had selected for the base case. With the largest spatial bandwidth selected, GTS identified 84 wells as redundant; of these 84 eighteen were in common with the 31 wells selected as the base case. Clearly the selection of spatial bandwidths can have a significant impact on GTS results when evaluating monitoring well redundancy.

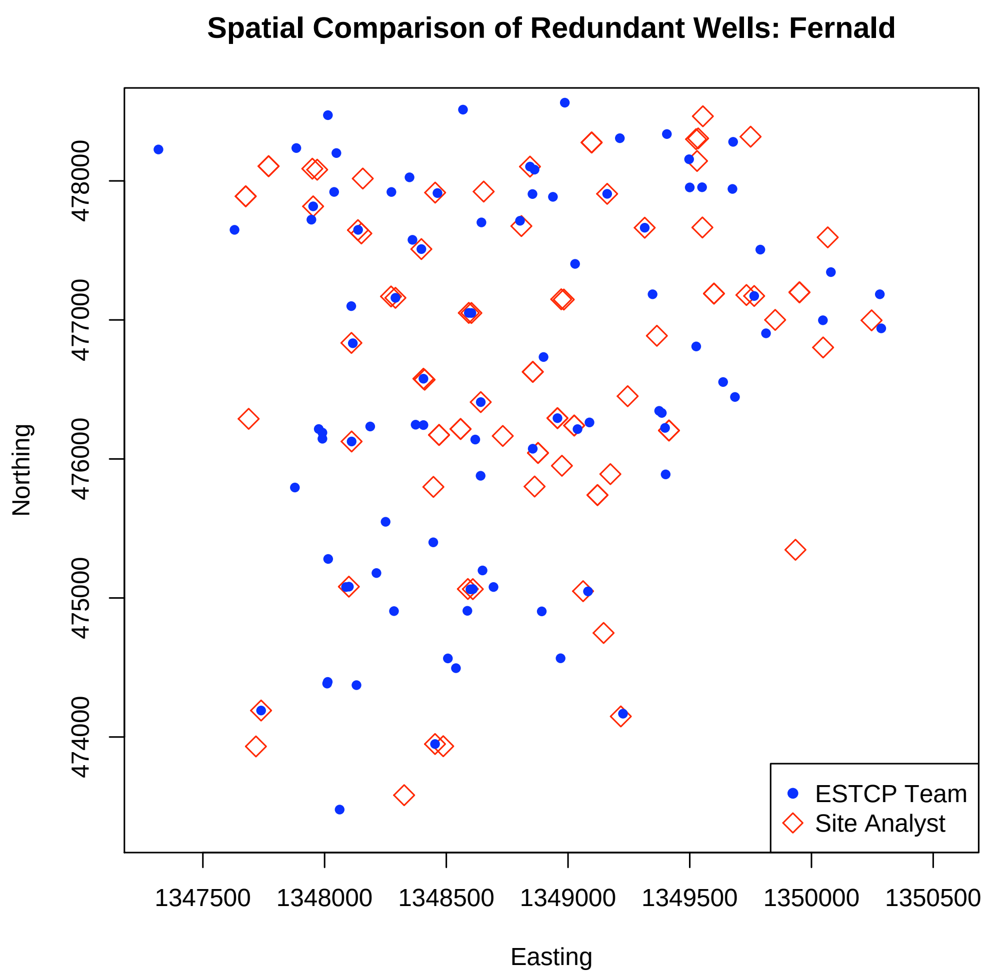
These results underscore two points: 1) the importance of starting any GTS optimization analysis with an accurate base-map, and 2) the fact that larger bandwidths lead to greater smoothing and less variation in concentration levels. Less variable maps tend to be easier to reproduce with fewer wells than maps with greater variation.

- In his sensitivity analysis considering the impact of 2D vs. 2.5D optimization, the Fernald analyst remarked that while the numbers of redundant wells in the two runs were similar (31 vs. 25 respectively of 153 eligible locations), "the specific wells selected as redundant [in the 2.5D case] were very different from the 2D analysis — only ten wells were identified by both the 2D and 2.5D analyses as redundant." While he did not provide the kind of comparative locational analysis discussed above, the result may point to nothing more than distinctly different spatial concentration patterns by aquifer zone. In that event, it would be surprising if GTS found nearly the same wells as redundant when treated as informing separate and distinct aquifers versus being treated as informing a single two-dimensional plane.
- Although the Fernald site analyst noted in his written report that using the default GTS spatial bandwidths in his 2D analysis produced 31 redundant wells (out of 153 eligible locations), the GTS-generated spatial optimization report he submitted listed 84 redundant locations (**Table 5-8**). Apparently this corresponded to the case when the analyst set all the spatial bandwidths to their maximum value, lessening the degree of variation in the Fernald base-maps. The analyst suggested that there seemed to be a remaining 'bug' in the software, since when he re-ran several optimizations using different parameter choices (including bandwidth values) — switching back and forth within the same project file — the optimized network status post-plots did not always seem to match the locations listed in the text report. In any event, the ESTCP project team could not do a detailed locational analysis using what the Fernald analyst called his 'base case' (i.e., 31 redundant wells, default GTS bandwidths), but instead had to analyze the submitted report.
- To tease out any similarities/differences between the analyses of the ESTCP project team and site analyst, a post-plot of the two sets of redundant wells is presented in **Figure 5-8**. Given the choice of the maximum spatial bandwidth in each case by the Fernald analyst, it is not surprising that he found a higher proportion of redundant wells than did the ESTCP project team. Furthermore, while there are some location matches (n = 18), there are many more non-matches.
- To quantify the degree of overlap, the redundant wells (n = 149) from the ESTCP project team analysis were compared against the redundant wells from the site analyst

(n = 84). Only 18 locations were the same in both optimization runs. Further, based on extensive Monte Carlo sampling of same-sized sets of locations from the full list of 153 unprotected Fernald wells (as employed by the site analyst), it was found that a randomly-picked set of 84 wells would average about 19 locations in common with the ESTCP project team redundant wells. The Monte Carlo well sets ranged from 10 to 28 wells in common, with a distribution indicating that an overlap of 18 wells was not at all statistically significant and no better than chance.

- The ESTCP project team also quantified the spatial placement of both sets of redundant wells. The mean interwell distance between nearest neighbor pairs from the two sets was 113 feet, compared to a typical mean interwell distance of 138 feet between nearest pairs in a randomly-selected test set of locations matched against the ESTCP project team redundant well set. In this case, fewer than 2.5% of the Monte Carlo-generated well sets had a mean interwell pair distance less than 113 feet, suggesting that — even when a) the second data set was a partially overlapping subset of the first, b) the bandwidths were artificially inflated, and c) the total numbers of redundant wells were quite different — GTS still tended to identify redundant wells from the same general areas of the site in both optimization runs.

**Figure 5-8. Spatial Comparison of Redundant Wells — Fernald**



### 5.5.6. Summary of Network Adequacy Evaluations

As an option in spatial optimization, GTS determines if any new well locations are warranted, known as the network adequacy analysis. This is done by locating areas within the site boundary exhibiting both high relative uncertainty (as indicated by large coefficients of variation) and higher average concentration levels. GTS then searches the site over a fine grid to identify suggested coordinates for new wells within these subareas of higher uncertainty. To ensure reproducibility, a new location must exhibit high relative uncertainty across multiple COCs (assuming more than one COC is being analyzed).

At each of the demonstration sites, the network adequacy results were correctly and easily computed. The default list of suggested locations, however, varied in usability. GTS cannot determine whether a new location might be sited at a physical obstruction or perhaps in an inaccessible area. GTS also does not account for available construction and monitoring budgets. For these reasons, the user is allowed to override any or all of the GTS recommended well locations. This feature allows GTS to be utilized flexibly in site planning. Post-plots of the new location results designate user-accepted locations in a different color than overridden locations, thus documenting both what was computed and what was deemed useful.

**Table 5-9** presents a summary of the numbers of suggested new wells, broken down by site and aquifer zone. At AFP44, GTS computed 24 recommended locations initially. Examination of the new well post-plots indicated that perhaps 13 of these locations should be eliminated, leaving 11 recommended new wells. Many of the eliminated wells were in close proximity either to other suggested wells or clusters of existing wells, and so represented probable redundancies. The case of aquifer zone SGZ was different: here it is known that the aquifer is only present over a small fraction of the boundary area. Any suggested wells placed outside the known extent of SGZ were overridden. The remaining two locations were kept, even though each was proximate to a cluster of existing wells. In practice, a knowledgeable site hydrogeologist might have overridden them also.

At NOP, 10 of 14 suggested wells were accepted by the ESTCP project team. Eliminated locations were in close proximity to existing wells. By contrast, when also including MC and TNT as COCs, along with RDX and TCE, the NOP site analyst found that GTS suggested 36 new well locations, the majority of which — especially for the SHALLOW layer — were located in the more sparsely-sampled northwestern section of the site. Some of these proposed wells were quite close to existing wells or even other newly proposed spots. Still, the addition of two highly non-detect COCs substantially changed the results. More detailed analysis suggested that two interdependent factors accounted for the differences:

1) In his final submitted analysis, due to time constraints, the NOP analyst did not override any of the suggested outliers identified by GTS. As discussed elsewhere, the variation in detection limits and high proportion of non-detects among some of the NOP analytes led GTS to flag way too many values as suspected outliers. Of almost 600 flagged records, the ESTCP project team decided that 9 were probable outliers, including 1 value each for MC and TNT. By excluding all the default outliers — a large number of which were non-detect values for TNT and MC — the NOP analyst increased the relative level of uncertainty in areas of the site with generally low concentrations of these chemicals, and thus the likelihood of GTS suggesting additional new wells.

2) By including TNT and MC in the optimization, despite their high proportions of non-detects and poorer optimization potential, the overall relative uncertainty across all the optimized chemicals — particularly in the northwestern quadrant — was increased relative to an analysis based solely on RDX and TCE. This coupled with factor (1) led to the larger number of new wells reported by the NOP analyst.

At Fernald, 4 new well locations were suggested in the single aquifer layer that was analyzed, and all were considered reasonable choices by the ESTCP project team. Similar to the redundancy analyses, the independent site analyst at Fernald arrived at somewhat different results. When running a 2D analysis similar to the ESTCP project team, the independent analyst found that no new well locations were suggested. However, the Fernald analyst used only 172 well locations in a more limited and central portion of the site, compared to the 376 (active) wells and more extensive site area analyzed by the ESTCP project team. Comparing the same areas, GTS did not recommend any new wells for either team, so the general results were consistent.

Interestingly, the Fernald analyst also did a network adequacy run as part of the 2.5D analysis he conducted, after supplying the missing aquifer zone information. In that case, 8 new well locations were suggested, 5 in the 'middle' layer and 3 in the 'bottom' layer. Note that this result underscores the importance of carefully deciding between a 2D and 2.5D approach within GTS. The map of relative uncertainty generated for each layer in a 2.5D analysis is based on the number, configuration, and concentration levels of wells in that layer. Comparing 2D to 2.5D on the same data will almost always give different results, as each layer in the 2.5D case will have fewer wells and often a different concentration pattern, generally leading to greater relative uncertainty (all other things being the same) and an increased need for new well locations.

Thus, it is not a 'flaw' in GTS that the network adequacy results for the 2D and 2.5D cases at Fernald were different. Rather, a) if separate aquifer layers exist, b) that information is available to the database, and c) the concentration patterns in each layer differ, a 2.5D analysis should generally be utilized, especially to target new wells to the depth and aquifer layer where they are most needed. Note, however, that the Fernald analyst also expressed surprise that many of the suggested new locations were proximate to existing wells. This can occur within GTS v1.0 for at least two reasons:

1) The algorithm utilized by the site analysts did not force new wells to be located only in unsampled areas of the site. Instead, new locations were suggested in any area with sufficient relative uncertainty and high enough concentration levels. Users were encouraged to review and, if necessary, override the suggested placements. GTS also indicated how many existing wells were in the local vicinity of each newly suggested well, both numerically and visually (on the post-plot) to aid these decisions.

2) GTS uses quantile local regression (QLR) in spatial mapping rather than, say, kriging. As a 'smoother' rather than an interpolator like kriging, there can be significant variability and hence uncertainty regarding average concentration levels even near existing well locations. This happens especially when the concentrations at closely spaced wells differ significantly (e.g., one high, one low). Contaminant levels in groundwater may not be spatially continuous (or at least smoothly so), depending on the complexity of the subsurface, preferential flowpaths, geochemical interactions with the subsurface soils, and so on. All of these factors can increase variability and

caused the previous algorithm in GTS to sometimes suggest new wells close to existing wells or well clusters in order to better characterize the contaminant patterns.

Despite these factors, the experience of the software testers led the ESTCP project team to slightly alter the computation of new wells so that — in the future — none would be suggested near existing locations. The current release version of GTS includes these changes.

**Table 5-9. Summary of Network Adequacy Results**

| Site | Aquifer Zone | Number of GTS-Suggested Wells | Number of Accepted New Wells |
|---|---|---|---|
| **AFP44** | LZ-UZLU | 4 | 3 |
| | UZUU | 9 | 6 |
| | SGZ | 11 | 2 |
| **NOP** | DEEP | 4 | 3 |
| | MEDIUM | 4 | 3 |
| | SHALLOW | 6 | 4 |
| **Fernald** | — | 4 | 4 |

### 5.5.7. Summary of Trend and Plume Flagging Results

GTS v1.0 provides an interface for importing new data into the program that can then be checked for possible anomalies relative to previously constructed baseline trends and base-maps. This import feature is distinct from the ability to incrementally append new data onto an existing database. The data imported for trend and/or plume flagging is also kept separate from the existing database.

To test the trend and plume flagging features (**Predict: Module E**), the most recent year's worth of sampling data was reserved from each test site, to be analyzed by the ESTCP project team. The goal was to determine whether the newer data was consistent with the older data, both temporally and spatially, and how well GTS would identify inconsistencies. To accomplish this goal at a temporal level, GTS constructs prediction bands around the baseline trends at contaminant-well pairs containing new data, linearly 'projects' (i.e., extrapolates) these bands to the new sampling dates, and then compares the newer measurements against the projected prediction band. Spatially, GTS computes an approximate prediction envelope around the base-map plume, and then interpolates the envelope to the coordinates of the new data to compare against the new concentration levels.

The independent site analysts were not asked to analyze this reserved data or to evaluate the trend and plume flagging features of GTS, though one tester at AFP44 did anyway. In general, both that tester and the ESTCP project team found the GTS algorithms for flagging anomalies to be somewhat too sensitive, resulting in more anomalies than made sense. According to the AFP44 tester:

> "Criteria to identify anomalies may be too sensitive; many of the flagged values when viewed in time series seemed reasonable and didn't merit attention in the context of flagrant violation of prediction bands."

**Table 5-10** offers a summary of the anomalies flagged by the ESTCP project team at each demonstration site. Despite the overly sensitive nature of the current GTS feature-set, users have the option to override any flagged anomaly, whether from trend flagging or plume flagging. So the final results of an analysis can be adjusted to better reflect the set of visually apparent anomalies. The principal reasons for 'too many' flagged anomalies include:

- Method of trend projection — GTS v1.0 projects the baseline trend and associated prediction band linearly, based on the direction of the most recent baseline slope. In fact, many of the trends 'flattened out' rather than continuing in the direction predicted by the baseline slope. A more conservative implementation of trend flagging would account for the possibility of a 'flat' future trend, in addition to the directional projection currently employed.
- Extrapolation is inherently difficult — Any trend or plume extrapolation into the future is inherently uncertain, more so the farther the extrapolation. GTS will 'fail' at this task some fraction of the time, no matter what projection method is utilized. For this reason, users are encouraged to review and override suggested anomalies whenever appropriate.
- Lower bounds of the plume envelopes were often not quite low enough — a number of essentially non-detect spatial anomalies fell just barely below the lower bound of the plume prediction envelope. An adjustment to the algorithm for constructing the prediction envelope may be needed.
- Anomalies are more than just outliers — the flagging algorithm in GTS is designed to identify not just obvious outliers, but also indications of temporal changes in trends or plumes, and even changes in detection/reporting limits for non-detects. To this end, some of the flagged anomalies may not be cause for alarm, but rather measurements to further investigate or document (e.g., conduct confirmation monitoring).
- Plume envelope is approximate — due to transformation bias in back-transforming from logit-space to concentration scale when constructing the plume envelope, its nominal confidence level of 99% is only approximate. This might account for a higher than expected number of spatial anomalies in some cases.

**Table 5-10. Summary of trend and plume anomalies identified by GTS**

| Site | # new data records imported | # default trend anomalies | # probable trend anomalies | # default plume anomalies | # probable plume anomalies |
|---|---|---|---|---|---|
| **AFP44** | 1154 | 126* | 48 | 198** | 128 |
| **NOP** | 1786 | 108 | 62 | 25 | 19 |
| **Fernald** | 2099 | 174 | 13 | 33 | 17 |
| **Total flagged/total probable (%)** | | 408 | 123 (30%) | 254 | 164 (65%) |

*The AFP44 tester found 141 trend anomalies based on an analysis that eliminated a larger default number of outliers during the outlier screening; the ESTCP project team eliminated many fewer outliers prior to screening for anomalies in Module E.

**The AFP44 tester found 186 plume anomalies.

### 5.5.8. Import/Export Features

GTS v1.0 allows the import of ASCII text files, with one of several possible delimiters between fields (e.g., tabs, commas, spaces). GTS also allows separate import of water level (i.e., hydraulic head or depth to water) files for the purpose of creating potentiometric surface maps. In addition, the data import function can be used to build incremental databases; that is, new data in the same format can be added onto an existing database through successive use of the import command. So existing data are not deleted; rather, new data are *appended* into the data structure. This enables rich data sets to be accumulated over time and analyzed at periodic intervals.

For the purposes of annotating maps and post-plots, GTS allows the user to import ESRI Shape files to be used as (static) graphic layers ‘underneath’ a given plot or map. The number of Shape files that can be imported is only limited by system memory. Note here that Shape files *cannot* be manipulated within GTS, as say, within a GIS application.

Users can also import a simple site boundary text file, which delineates the vertices of a polygonal site boundary. In the current version of GTS, such a boundary is used not only to annotate the graphics, but also to determine where map estimates should be made and what constitutes the analysis area of interest.

The most significant drawback to GTS import is the number and type of fields that are required to run an optimization. Given that GTS was originally developed for the Air Force, its input structure is based on standard ERPIMS conventions and field names. Any user must therefore ensure that his or her data is formatted according to these conventions. Altogether, 22 different data fields are required in GTS; some of these may have missing entries if

complementary fields are populated (e.g., only one pair of the well screen depth fields SBD/SED and IBDEPTH/IEDEPTH need by populated; some databases tend to use the first pair, some the second). If potentiometric surface maps are desired, another three fields are required as part of either the main analytic database, or as part of a separate water level file.

Despite the large, required data structure, there is no requirement for data fields to be listed in any particular order. As long as the field names in the data file header match the GTS field names, the data are 'slotted' into the right places within the internal SQLite database. Still, the experience of GTS testers during this project with data import varied considerably, with some have significant difficulties in getting GTS to correctly import their data. Relevant comments included:

> "Data import is very involved and could be simplified; this is the single issue that could limit application to a wide audience." (AFP44)

> "My initial attempts at loading data files failed — no error messages were thrown, there was no indication that something was wrong with the files, but GTS did not allow me to work with the data. After much experimentation I found that if I completely filled all blank fields, the load would be successful." (Fernald)

> "I struggled with data import. My struggles were two-fold: manipulating the Fernald data so that it satisfied GTS's data paradigm, and producing input files that GTS would accept." (Fernald)

As a footnote, the tester at Fernald decided to manipulate the prepared input data well beyond the common data package that was supplied to both the site testers and the ESTCP project team. Much of this manipulation related to two factors: 1) the lack of adequate aquifer zone designations within the original data, and 2) the attempt to properly account for temporary DPT sampling locations within the context of long-term monitoring.

GTS has particular export capabilities, but also drawbacks in this regard. On the plus side, each report in GTS (covering the results of a significant step in the analysis) can be exported to HTML and viewed in any standard web browser. These reports can also be easily sorted according to the report field headers. GTS also exports two text files of optimization results that are critical to completing the cost-benefit analysis using the GTS cost comparison calculator: the first provides a location-by-location listing of the temporary and spatial redundancy analyses (i.e., whether that well was flagged as redundant and the recommended sampling frequency if optimized temporally), while the second gives a listing of new wells recommended by GTS and their approximate coordinates. Both of these results files can be imported into Excel or another spreadsheet application for further summarizing or manipulation; they also must be imported into the GTS cost comparison calculator to derive the overall return on investment (ROI) associated with GTS optimization.

At the end of a project, users can document the database used in their analysis by exporting it to a tab-delimited text file. Note that this file contains not only the imported data, but also several 'derived' fields constructed by GTS internally to aid the analysis.

Unfortunately, GTS does not currently allow for graphics to be exported to image files. Initially, this capability had to be skipped due to the rather large number of graphics associated

with a given analysis and the need to incorporate batch exporting of related graphics. The GTS project files were also designed to be somewhat self-contained, so that all the graphics from an analysis could be re-visited by reloading the project. While the project files work as planned, users desiring to export graphics for other purposes must perform a screen capture and paste the graphic into an image-editing program. Relevant comments concerning graphical export included:

> "There is not a way to save some of the graphics output, other than to do a screen capture, pasting the object into Paint or similar program and then saving as a JPEG file. The ability to save graphics would be very helpful for documenting and reporting the analysis results." (NOP)

> "Reporting, in particular, the numerous graphics generated as output should be wholesale exported into a file for viewing and analysis; not sure what format would be best or universal." (AFP44)

### 5.5.9. Computation Time/Level of Effort

A summary of the amount of time it takes to apply GTS v1.0 is indicated in **Table 5-11**. This includes computation time primarily, though data preparation mostly encompasses manual labor. The amount of time required to run the optimization steps in GTS (temporal and spatial) varies considerably, according to the size of the network, amount of historical sampling data per well, and the hydrogeologic configuration of the site (i.e., number of separate aquifers and number of critical contaminants). Additional time is required to interpret and export results, as well as import results into the GTS cost comparison calculator to generate ROI.

**Table 5-11. General Summary of Time Required to Run GTS v1.0**

| Task | Time | Comments |
|---|---|---|
| Data Cleanup, Screening, Formatting | One to several days | Similar effort needed with other LTMO software; effort is primarily manual labor |
| Outlier screening (Module A) | Minutes to Hours** | Minutes to compute; review of a large number of outliers may require significant time (**) |
| COC ranking, horizon analysis (Module B) | Minutes | |
| Baseline trends, Base-maps (Module C) | Minutes to Hours** | Minutes to < 1 hour to compute; more time may be needed for user to review/select temporal & spatial bandwidths (**) |
| Temporal Optimization — Temporal Variogram (Module D) | Seconds to Minutes | |
| Temporal Optimization — Iterative Thinning (Module D) | Minutes to Hours | Wells with long data histories take more time; Time increases linearly with number of wells being analyzed |
| Spatial Optimization — Redundancy Search (Module D) | Minutes to Hours** | Time varies ~linearly with number of wells, number of contaminants, number of time slices, and number of separate aquifers; very large sites could require days of computing time (**) |
| Spatial Optimization — Network Adequacy (Module D) | Minutes | |
| Trend flagging (Module E) | Minutes | Time increases linearly with number of new records being analyzed |
| Plume flagging (Module E) | Minutes | Time increases linearly with number of new records being analyzed |

The two most computationally intensive steps in any GTS evaluation are temporal optimization by iterative thinning and the spatial redundancy search using the GTSmart algorithm. **Table 5-12** provides a rough indication of the level of computational effort needed by the ESTCP project team to accomplish each of these steps at the three demonstration sites.

**Table 5-12. GTS Computational Time at Three Test Sites**

| Site | Data Configuration | Iterative Thinning | | GTSmart Redundancy Search | |
|---|---|---|---|---|---|
| | | **Computation Time** | **Comments** | **Computation Time** | **Comments** |
| **AFP44** | 3 Aquifers, 208 wells, 4 COCs, 6 time slices | ~4 hrs | 342 COC-well pairs; <1 minute per pair | 14-15 hrs | 57 COC-zone-time slice triples; ~49 eligible wells per triple; ~15 minutes per optimization problem |
| **NOP** | 3 Aquifers, 250 wells, 2 COCs, 7 time slices | 35-40 minutes | 57 COC-well pairs; <1 minute per pair | 10-11 hrs | 42 COC-zone-time slice triples; ~39 eligible wells per triple; ~15 minutes per optimization problem |
| **Fernald** | 1 Aquifer, 467 wells, 1 COC, 4 time slices | 2.5 hrs | 217 COC-well pairs; <1 minute per pair | 6 hrs | 4 COC-time slice pairs; 209 eligible wells per pair; ~90 minutes per optimization problem |

## 5.6 SAMPLING METHODS

No samples were collected by the ESTCP project team as part of this project. Data utilized were from sampling results previously obtained by the demonstration sites under their site-specific sampling plans.

## 5.7 SAMPLING RESULTS

Again, no samples were collected by the ESTCP project team as part of this project. Data utilized were from sampling results previously obtained by the demonstration sites under their site-specific sampling plans.

# 6.0 PERFORMANCE ASSESSMENT

## 6.1 QUALITATIVE PERFORMANCE OBJECTIVES

### 6.1.1 Software Ease of Use

The expected performance metric is that GTS is easy to use and navigate by prospective users, and that the GTS interface is well-designed and readily understood. The purpose of this performance objective is to indicate whether a mid-level analyst (i.e., one with some statistical and hydrogeological background) will be able to apply GTS to their site. During the demonstration, this objective was evaluated by having independent site analysts use GTS at the three test sites and report on their findings and experiences with the software. Although most of the site analysts had some previous exposure to MAROS, none had ever used the upgraded version of GTS nor was any user training on GTS provided, other than weekly phone support for questions. As documented in **Section 5.5.2**, navigation and use of the software was found to be straightforward and quickly understood. Installation was also generally straightforward, once proper administrative privileges were granted. Based on application of GTS by these independent analysts at the three demonstration sites, this performance objective was met.

### 6.1.2 Users Guide Ease of Use

The expected performance metric is that prospective users find the GTS users guide/manual easy to utilize and understand, and that it is helpful in directing them on how to operate GTS and interpret its output. The purpose of this performance objective is to ensure that the software documentation for GTS is adequate and helpful in performing optimization analyses. The objective was assessed by gathering feedback on the users guide from software testers and the independent site analysts who used GTS at the three demonstration sites. In general, users reported that the manual was well-written and straightforward in explaining how to operate each of the GTS modules. Comments were made by some testers that the GTS manual did not provide as much desired information on technical details regarding the GTS computational algorithms or how GTS derived certain results. Some users also desired additional guidance on how to correctly interpret GTS output/results. Based on this feedback, the performance objective was partially met.

### 6.1.3 Interpretation of Graphical Output

The expected performance metric is that prospective users will readily understand and correctly interpret GTS graphics and plots, perhaps in conjunction with consulting the GTS users guide. Since GTS incorporates a ‘heavy dose’ of statistical graphics to convey optimization results, the purpose of this objective is to ensure that the graphics are both helpful and readily understood by the typical user. Direct feedback from software testers and the independent site analysts was solicited in order to evaluate this objective. In general, users found the graphics to be well-executed and helpful in conveying results. Some users suggested specific improvements to the program’s graphics capabilities, such as improved legends or greater user control over

symbols and colors. However, all users indicated good ability to use and interpret the existing graphics. Based on this feedback, the performance objective was met.

### 6.1.4 Software Reliability

The expected performance metric is that the final public release of GTS v1.0 does not exhibit any significant bugs or software glitches that impact/impede its ability to perform useful optimization analyses. The purpose of this objective is to identify whether there are any reliability issues associated with future use of the software. This objective was evaluated by testing the upgraded GTS software at three distinct sites, representing a variety of different conditions and data configurations, and by gathering direct feedback on software performance from the independent site analysts, as well as other interested software testers who participated in the ESTCP project team weekly conference calls.

Since GTS v1.0 represents a major upgrade and overhaul of the previous GTS beta software, many (i.e., hundreds) bugs, glitches, and crashes were encountered and reported by testers during this project. In all, 34 distinct alpha and beta builds of GTS were tested over the three-year period, including 7 in 2008, 19 in 2009, and another 8 in 2010. Each build addressed multiple issues that were identified by testers. However, users also noted that by the final release in summer 2010, there were no significant bugs remaining. All testers were able to complete a start-to-finish optimization analysis without any crashes, bugs, or analysis-impeding issues. Thus, this performance objective was met.

### 6.1.5 Release GTS as Stand-Alone, Public Freeware

The expected performance metric is that GTS will be completely free to use, and that it will be a stand-alone desktop application installed using a single executable file (.exe). The purpose of this objective is to ensure that GTS — funded by public moneys — can be used free of charge by the public. And further, that the distribution and installation of GTS are made as uncomplicated as possible. This objective was evaluated by observing the characteristics of the GTS v1.0 end product. The design requirements for GTS mandated that free-to-use and/or open source software components be utilized in building the software. Many ideas were considered before settling on an architecture consisting of four major software technologies: 1) the open-source R statistical computing environment (www.r-project.org); 2) the open-source SQLite database tool; 3) the open-source QT interface development environment (IDE); and 4) the license-free MatLab runtime environment. Each of these pieces was critical to some aspect of GTS performance or functionality — R for statistical computing and optimization, SQLite for data housing and manipulation, QT for building the user interface, and MatLab for statistical graphics.

Because existing software technologies were leveraged in constructing GTS, a single installer was desired to avoid users having to install multiple, separate components with differing requirements. To this end, all the GTS component technologies were bundled together into a single executable (.exe), with the exception of the Excel-based cost comparison calculator spreadsheet. The installer loads each component of GTS, including the GTS application itself, onto a desktop computer running Windows XP, with minimal input from the user. Although first-time installation can take up to an hour, updates are much more rapid as components that are already present do not need to be re-installed.

All of the major components used in GTS are open-source freeware, with the exception of MatLab. Because SAIC, part of the ESTCP project team, owns a MatLab developers license, it can freely distribute a license-free, cost-free executable of the MatLab runtime environment. This runtime environment is bundled into GTS v1.0. As far as the cost comparison calculator, Microsoft's Excel is, of course, not freeware, and so could not be bundled into the GTS executable. However, it is practically ubiquitous within the enterprise software arena. Any user with Excel on their computer can therefore access and run the GTS cost comparison calculator spreadsheet without any additional charge. In a future version of GTS, it is planned for the cost calculator to be coded directly into the interface, with no need for Excel. However, even at present, almost no, if any, prospective users will need to pay anything to run GTS. Based on this architecture and design, the performance objective is met.

### 6.1.6 Accessible to Non-Experts

The expected performance metric is that GTS can be successfully run and interpreted by mid-level analysts. A mid-level analyst was defined for purposes of this demonstration as someone with some college-level background or professional experience in statistics, geostatistics, and hydrogeology, but who was not an expert in statistics/geostatistics. The purpose of the performance objective is to ensure that GTS can be successfully run by likely prospective users, and that the labor costs associated with its use are not prohibitive. This was evaluated by having independent, non-expert testers run the software at the three demonstration sites and directly soliciting their feedback. Overall, none of the independent software testers were professional statisticians or geostatisticians, although the Fernald tester had previous professional experience in doing statistical analyses. All of the testers were likewise able to successfully complete one or more optimization analyses of their site data. Further, three testers commented in their evaluations that GTS could be reasonably navigated and applied by a professional with hydrogeological experience and some statistics background. Based on this feedback and their successful analyses of the demonstration site data sets, this objective is met.

### 6.1.7 Robustness of Software

The expected performance metric is that GTS can be applied across sites with a variety of contaminants of concern (COCs), hydrogeologic terranes, remedial solutions, etc. The purpose of this objective is to ensure that GTS is applicable to a large number of potential sites and conditions. This was evaluated by applying GTS to three different test sites, representing different branches of the government or DoD, and covering a range of differing conditions. In addition, two versions of the AFP44 database were tested by the ESTCP project team, and multiple data configurations were tested at each site by the independent analysts. Further, GTS was applied during the demonstration period by other interested software testers to several other sites, including Paducah, KY (DoE), Cape Canaveral (Air Force), Andrews AFB, Tinker AFB, and Fort Dix (Army).

Regarding the three ESTCP demonstration sites, **Table 4-1** and **Section 4.0** document the variety of contaminants, numbers of wells, and aquifers optimized by GTS, including metals, organics, and radiologic parameters embedded within either alluvial valleys or buried valley glacial outwash aquifer systems, and with well sets ranging from 200+ to over 400. All of the test sites were undergoing or had undergone some type of remedial activity. Since spatial

optimization in GTS is not ‘plume specific,’ it does not require that the plume(s) be ‘stable’ over time, only that maps can be estimated over a series of temporal ‘snapshots’ (i.e., time slices). This allows for optimization at sites where concentration levels and patterns are actively changing, as indeed seen at the three demonstration sites.

The most important assumption (and limitation) of GTS is common to any geospatial mapping tool: each aquifer or aquifer layer is assumed to be spatially and hydraulically connected, leading to spatially continuous concentration patterns. Subsurface environments that are highly fractured or with strongly preferential pathways may not be good candidates for a GTS spatial analysis. On the other hand, GTS temporal optimization — particularly the well-specific iterative thinning feature — was shown to be applicable in any hydrogeologic environment, since it does not depend on spatial continuity, and is especially useful at sites with complex or seasonal trends. And, since GTS is modular by design, users can flexibly apply either or both of the spatial and temporal optimization features, depending on site-specific conditions. All in all, the successful application of GTS to three very distinct test sites shows that the performance objective is met.

### 6.1.8 Water Level-Aided Mapping

The expected performance metric is that GTS can optionally estimate concentration maps using water level data as a covariate (and proxy for groundwater flow direction and potential). The purpose of this objective is to identify whether GTS can build more accurate and useful base-maps by simultaneously utilizing both analytic concentration data and water level measurements. Unfortunately, internal development and testing of this feature on some of the test site data led to inconclusive results. Available resources and the project timetable did not allow for the development of additional improvements or deployment within the GTS interface. Thus the stated performance objective was not met. However, this work led to GTS incorporating a fairly robust mapping of the potentiometric surface as an added feature, something of a by-product of the original objective. Users commented that these water level maps — displayed in a temporal series by time slice — are quite useful as characterization tools in and of themselves.

## 6.2 QUANTITATIVE PERFORMANCE OBJECTIVES

### 6.2.1 Software Ease of Use

The expected performance metric is that GTS is easy to operate by prospective users, and testers will encounter few operational difficulties. The purpose of this objective is to ensure that GTS is set-up in a manner that is conducive to use by prospective analysts. This was evaluated quantitatively by cataloging the number and types of operational problems/issues encountered by the independent Site analysts. **Table 6-1** lists the issues reported by type and number of similar reports.

The biggest operational issues included installation of GTS on government-owned computers and the variety of software bugs and crashes encountered while operating early beta versions of GTS. Installation of new desktop software on DoD or other government computers often requires specific Administrator privileges. This difficulty is not unique to GTS but was

reported by each of the testers. A more serious difficulty was the fact that due to the lengthy period of development needed to overhaul GTS and eliminate bugs from the software, there was not enough calendar time during the ESTCP project to wait to begin the case studies at the three demonstration sites until a completely stable version of GTS had been built. Instead, the case study analyses overlapped the GTS development phase, with two important consequences:

- The independent site analysts were given beta versions of GTS to perform their analyses. Since each beta version still possessed a number of unknown bugs, the testers all encountered new problems or bugs that sometimes crashed the software. In addition, as identified bugs were fixed and new versions of GTS built, testers were forced to install updates to the software and sometimes re-do portions of their analysis. At NOP, this became a significant issue, since the independent analyst had to wait for his IT staff to be able to schedule a GTS update, given the Administrator privileges needed.
- Beta testing of GTS was more extensive than it would have been had not the development and demonstration phases of the project overlapped. While this posed an operational difficulty for the site analysts, it also allowed a larger number of testers to 'bang on' the software before final release.

Four other issues were reported by more than one tester:

- Data importing — the process for importing data was considered too complicated by some users, requiring too many fields or too specific a format. One user was not clear as to which fields were required vs. optional. One had difficulty loading a boundary file, though this was apparently due to insufficient guidance in the users manual as to the type of boundary file that GTS accepts.
- Graphics — some users commented on the inability in GTS to export plots and maps to common graphical formats, either singly or in batches. Instead, users are currently forced to capture individual screenshots of desired graphics and then import or modify those screenshots in other programs.
- Optimization — users commented on the lengthy times needed for iterative thinning and especially for spatial optimization in GTS, perhaps requiring overnight computer runs. This limited their ability to test different variations of an optimization, such as by changing input parameters.
- Outliers — some users found the GTS criteria for identifying potential outliers to be too sensitive, thus generating more outliers than reasonably existed. At large sites, this in turn entailed significant effort for user review and possible override of data points that were really non-outliers.

Despite these operational issues and difficulties, all testers rated the GTS interface as highly usable, easy to navigate, and readily understood. Based on this feedback, this objective was partially met.

**Table 6-1. Summary of Operational Difficulties Encountered by Software Testers**

| Type of Operational Difficulty | Description of Difficulty | # of Reports* |
|---|---|---|
| Installation | Lack of Administrator Privileges made installation difficult or lengthy | +++ |
| Bugs in Beta Testing | Several bugs and/or crashes encountered while operating beta versions of GTS | +++ |
| Data Importing | Importing data is very involved/too complicated | ++ |
| | Zero/negative (radionuclide) data not handled by GTS without user adjustment | + |
| | Trouble loading boundary file | + |
| Graphics | No way to export graphics into other programs without creating screenshots | ++ |
| | Legends do not display correctly on 64-bit machine | + |
| User Interface | Difficulties in switching back and forth (i.e., navigating the interface) during an analysis when changing parameters/settings and/or re-doing computations | + |
| | Keyboard shortcuts (e.g., Control-X) do not work with highlighted material | + |
| Optimization | Optimization runs took a long time | ++ |
| | Trouble deselecting COCs for optimization | + |
| Outlier Analysis | Tedious to review outliers at sites with many wells | + |
| | Criteria for identifying outliers too sensitive | ++ |
| Trend/Plume Flagging | Criteria for identifying anomalies too sensitive | + |

* Each '+' symbol represents one distinct report

### 6.2.2 Reproducibility of Temporal Optimization

The expected performance metric is that GTS produces consistent, repeatable results during temporal optimization, such that different users analyzing the same data should generate substantially similar optimal sampling frequencies. The purpose of this objective is to determine whether the temporal optimization algorithms and features in GTS give valid results that can be replicated across multiple runs of the software or across multiple users. As detailed in **Section 5.5.4**, the optimized sampling intervals derived using iterative thinning at two of the sites were very similar when comparing the ESTCP project team's results with those of the independent site analysts. At both AFP44 and NOP, identical recommendations were computed for the overall, site-wide sampling interval, while the aquifer zone-specific intervals were identical in 4 of 6 cases, only differing by one quarter (1Q = 90 days) in the other two. At Fernald, the independent analyst computed both the baseline sampling interval and the optimized sampling interval as longer by a quarter than the ESTCP project team did. This did not reflect a lack of validity in the GTS results, but rather that the Fernald analyst used a fairly different subset of the original data package supplied to each site, and that that subset exhibited longer average baseline sampling intervals.

Additional evidence of the repeatability of GTS temporal results was provided by the histograms (**Figure 5-5**) comparing patterns of optimal sampling intervals at individual wells. Despite differing user choices with respect to temporal bandwidths, confirmed outliers, and COCs, the comparative distributions of sampling intervals exhibit very similar quantiles at AFP44, and strong similarity at NOP. A Kolmogorov-Smirnov test of the hypothesis that both sets of optimal sampling intervals at AFP44 were drawn from a common distribution is clearly not significant, with approximate p-value $\approx 0.99$. A similar test at NOP is also not significant, with approximate p-value $\approx 0.53$. Thus, no clear statistical difference is evident at either site, even though the NOP analyst included two COCs (MC and TNT) in his analysis that were excluded by the ESTCP project team.

By contrast, the differing data sets used at Fernald by the ESTCP project team and independent analyst led to distinct distributions of optimal well-specific sampling intervals. The Fernald analyst found generally longer optimal intervals, and the Kolmogorov-Smirnov test of a common distribution was highly significant ($p < 0.0001$), underscoring the different patterns that were computed.

Finally, it should be noted that iterative thinning was run on both versions of the AFP44 database by the ESTCP project team, though not discussed in **Section 5.5.4**. Given that the only difference in this case was the aquifer zone classification of certain wells — which does not impact iterative thinning — it is not surprising that the site-wide and aquifer zone-specific sampling interval recommendations from both runs were identical, only differing very occasionally at the individual well level. Based on these comparisons, this performance objective is met.

### 6.2.3 Reproducibility of Spatial Optimization

The expected performance metric is that GTS produces consistent, repeatable results during spatial optimization, such that different users analyzing the same data should generate substantially similar optimal sampling networks. The purpose of this objective is to determine whether the spatial optimization algorithms and features in GTS give valid results that can be

replicated across multiple runs of the software or across multiple users. As detailed in **Section 5.5.5**, there was a close similarity at AFP44 in the percentages of redundant wells identified, whether the ESTCP project team used Version 1 of the database (24%), Version 2 of the database (26%), or whether the independent site analysts did the analysis (28% and 20%). At NOP, there was a much larger difference between the ESTCP project team (16%) and the Site analyst (45%), largely attributable to the additional COCs optimized by the NOP analyst. When the independent analyst used the same COCs as the ESTCP project team, he arrived at a fairly similar redundancy percentage of 20%.

Additionally, analysis of the specific wells deemed redundant and the spatial pattern of redundant wells revealed substantial overlap and locational 'closeness' at both AFP44 and NOP. Compared against Monte Carlo sampling of random, unprotected well subsets, the actual subsets of redundant wells in Versions 1 and 2 of the AFP44 database exhibited a highly statistically significant number of locations in common. This was also true of the comparison between the ESTCP project team results and that of the AFP44 site analyst, as well as the comparison of common locations at NOP between the ESTCP project team and the site analyst there. Monte Carlo testing further indicated that redundant wells at both sites were generally being selected from the same subareas, as indicated by highly statistically significant, low mean interwell distances between nearest neighbor location pairs (each pair formed from one well in each set of redundant locations).

The results for Fernald were exceptional, largely due to the differing data sets utilized by the ESTCP project team and independent analyst. When the Fernald analyst used the default GTS spatial bandwidths, he found less redundancy among a much smaller subset of wells and DPT locations than the ESTCP project team did using a much larger set of locations. When he re-did the analysis using the maximum spatial bandwidth for each map, the Fernald analyst found a higher level of redundancy than did the ESTCP project team.

While a detailed locational analysis could not be done on the Fernald analyst's 'base case,' an analysis of the maximum bandwidth results found that though the number of redundant wells 'matched' between the ESTCP project team and independent analyst was *not* significant, the relative 'closeness' or spatial similarity was statistically significant ($p < 0.025$). This occurred despite the differing data sets and choices of bandwidth parameters.

All in all, with the caveat that the choice of COCs can make a large difference in optimization results — especially if a user attempts to optimize COCs with very high non-detect rates and low optimization potential — the numeric similarity in spatial redundancy results indicates that this performance objective is met, to the degree it could be ascertained.

### 6.2.4 Predictability

The expected performance metric is that the Predict Module in GTS will successfully project/extrapolate baseline trend and plume estimates to encompass at least 90% of near future measurements collected at the same site. The purpose of this performance objective is to determine whether GTS can accurately identify 'anomalous' measurements, values that by definition are significantly different from previous trends and therefore should occur infrequently, especially if the future groundwater samples are collected close in time to the existing historical database. The Predict Module in GTS v1.0 makes two kinds of extrapolations: 1) Baseline trends are extended linearly to the sampling dates of new measurements, based on

the most recent slope and magnitude of each baseline trend. A prediction band is also estimated around the projected trend. 2) Base-maps are projected by estimating a prediction envelope around the plume for each time slice. The plumes and their envelopes are then separately averaged across time slices to yield a joint prediction envelope around the predicted plume. New measurements falling outside the extrapolated prediction band are deemed 'trend anomalies.' Likewise, those measurements falling outside the predicted plume envelope are denoted 'plume anomalies.'

To evaluate this objective, the final and most recent year of sampling data was reserved at each demonstration site for testing of the 'trend flagging' and 'plume flagging' features of the Predict Module. That is, all the previous years of historical data were utilized to construct baseline trends and base-maps (as well as to perform the optimization studies), while the final year was treated in the demonstration as a set of 'new, future measurements.' As detailed in **Section 5.5.7**, trend anomalies were detected in 11% of the reserved AFP44 data, 6% of the reserved NOP data, and 8% of the reserved Fernald data, for an overall rate of 8%. Plume anomalies were found respectively in 17%, 1% and 2% of the same reserved data sets, for an overall rate of 5%. Thus, while slightly less than 90% of the new measurements were correctly predicted at AFP44, the target was easily met at the other two sites, and for the project as a whole. So the stated objective appeared to be met.

Nevertheless, both the ESTCP project team and some of the independent analysts commented that too many 'anomalies' were apparently flagged, a conclusion born out by further examination of the anomaly time series plots and plume prediction envelope limits. In **Table 5-10**, it was determined that perhaps only 30% of the trend anomalies and 65% of the plume anomalies were values deserving further investigation or verification. Improvements were also planned to the Predict Module algorithms for a future version of GTS. So on this score, the performance objective is only partially met.

### 6.2.5 Optimization Effectiveness

The expected performance metric is that GTS is able to identify significant redundancy in larger groundwater monitoring networks and that it can generate optimized sampling programs. The purpose behind this objective is to ensure that GTS is 'worth its salt' as an optimization tool, in that it can identify redundancies when they exist and generate relevant potential cost savings. The objective was assessed by computing the degrees of temporal and spatial redundancy identified at each demonstration site, and translating these redundancies into estimated cost savings via the GTS cost comparison calculator. As discussed in **Sections 5.5.4** and **5.5.5**, each of the demonstration sites had a large groundwater monitoring network with significant annual monitoring expense. The number of wells analyzed at each site included 208 wells at AFP44, 250 wells at NOP, and a combination of 467 wells and DPT locations at Fernald. Optimized temporally by iterative thinning, GTS proposed a reduction in sampling frequency of approximately 75% at AFP44, 50% at NOP, and 67% at Fernald. Further, levels of spatial redundancy were estimated at 24-26% for AFP44, 16% for NOP, and 40% at Fernald. Each of these redundancies translates into a significant reduction in annual monitoring expense, particularly the decreases in minimum sampling frequency.

At each demonstration site, the iterative thinning results were translated by GTS into recommended optimal sampling intervals, not only on a site-wide basis, but also as

recommendations for each aquifer zone, and, if so desired, as well-specific recommendations for each separate location. In a similar vein, spatial redundancies identified via the GTSmart algorithm were translated into optimal sampling networks, with a recommended list of 'essential' wells at each site.

Finally, using the GTS cost comparison calculator (as discussed in **Section 7.3**), the optimized sampling programs computed using the software would translate into substantial annual cost savings compared to the current monitoring programs. At AFP44, the estimated savings would be 44% of an annual baseline program cost of $434K or approximately $191K per year. At NOP, the savings were estimated at 39% of an annual baseline program cost of $465K or approximately $181K per year. And at Fernald, savings were projected at 45% of an annual baseline program cost of $360K or approximately $162K per year. Clearly, this objective is met.

### 6.2.6 Accuracy

The expected performance metric is that there is good numerical/statistical agreement between the baseline trends and base-maps GTS constructs and the original measurements from which they are estimated. In other words, the baseline trends and base-maps accurately reflect or represent the underlying data. The purpose behind this objective is to ensure that GTS does not optimize a false or unrepresentative baseline. As noted in **Section 5.2**, GTS identifies redundancy based on its ability to accurately reconstruct concentration trends and maps. But if the starting point for optimization — either a baseline trend or base-map — does not reflect actual site conditions, there is no reason to trust reconstructions of inaccurate trends or maps based on supposedly 'optimized' sample sets. How, for instance, can a well location be considered redundant if a map to which it contributes is substantially 'off target?'

To evaluate this objective, two key steps were taken: 1) extensive internal testing of the trend and map algorithms developed for the GTS v1.0 upgrade, including analysis of trend and map accuracy through minimization of weighted residuals; and 2) building interface elements into GTS to allow users to check trend and map fits, and to override the GTS default temporal and spatial bandwidth selections. Since GTS uses local regression to estimate trends and maps, its trend-making and map-making tools are 'smoothers' rather than interpolators. Regression is readily understood with respect to trends, but less common in geospatial map-making, where kriging is better known. As an interpolator, ordinary point kriging estimates always precisely match the observed data, so there are no residuals. Nevertheless, kriging-based concentration estimates made *between* known data may or may not accurately reflect the overall spatial pattern or continuity in concentration values, nor are most measured groundwater concentration levels known with great precision (typically, USEPA analytical methods allow an RPD ranging from 15 to 30 percent). So interpolation via kriging can readily lead to inaccurate maps, despite the lack of residuals. Even smoothing-based methods such as local regression can also be adversely impacted if the analytical data are too 'noisy' (i.e., low accuracy due to a wide range of percent recovery).

By contrast, local regression rarely matches the observed data, even as a linear regression trend may not precisely 'hit' any of the observed data points. There are always residual differences (or error) between the regression fit and the measured concentrations. Nevertheless, it is designed to accurately capture the nature and direction of the trend, even as it attempts to

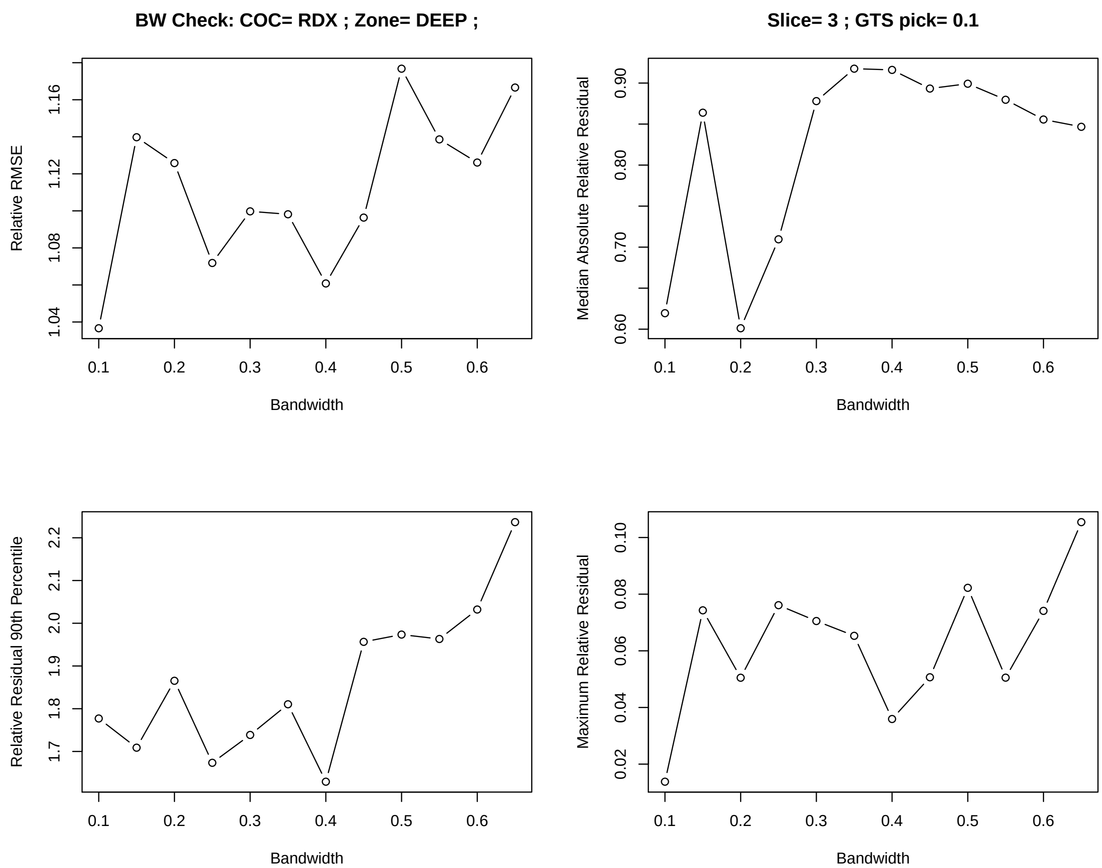
minimize the residual error. GTS v1.0 employs this concept in both trend fitting and map estimation.

To ensure accurate trends, internal testing of the GTS algorithms was done using a variety of data sets, including data from the three demonstration sites. To minimize residual error between a given trend and its observed data, the GTS algorithm was designed to explore a series of possible bandwidths, with the default bandwidth value chosen to jointly best minimize a) Mallows CP criterion (this is closely related to a scaled sum of squared residuals); b) average bias in the residuals; c) skewness in the residuals; d) residual non-normality; and e) correlation between the residuals and either the fitted concentrations or time of sampling. In the event of a tie between potential bandwidths, more weight was assigned to the Mallows CP and average bias diagnostic criteria.

This internal residual checking enables GTS to select the best-fitting local regression trend in terms of residual error. However, it does not always work to select the best-fitting trend. Occasionally, a trend may be ‘close’ to its observed data and yet be radically inaccurate *between* certain sampling dates, as judged visually by the overall data pattern. To ensure accuracy in these cases — since they tend mostly to occur between more widely-spaced sampling events — GTS does both a sampling gap analysis, which attempts to eliminate data from trend fitting that occur prior to large gap between measurements, and allows the user to visually check and override the default bandwidth when necessary via the ‘check bandwidth’ interface. Note in this regard that complex, non-linear trend fitting is an inherently difficult statistical task. Two testers noted examples in their evaluations of wildly inaccurate default GTS trends (see **Appendices D** and **E**). This was seen as a drawback to GTS. In fact, in the very examples cited, the GTS interface offers alternate, much more ‘accurate’ (and visually pleasing) trends that can be easily selected by the user.

To ensure accurate maps in GTS, similar internal testing was conducted to minimize the residual spatial error. In this case, as described in **Section 5.2**, the residuals were logged relative concentration errors, weighted by spatial density. The default bandwidth selection algorithm attempted to jointly best minimize: a) the root mean squared error (RMSE); b) the median absolute deviation in relative residuals; c) the 90$^{th}$ percentile of the absolute relative residual distribution; and d) the maximum absolute deviation. Ties in prospective bandwidths were broken by giving greatest weight to the RMSE and 90$^{th}$ percentile diagnostic criteria. An example diagram illustrating the minimization of these diagnostic criteria is shown in **Figure 6-1**.

**Figure 6-1. Example of Diagnostic Spatial Bandwidth Selection**




Like the trend fitting, maps with minimal residual error at observed wells may be inaccurate *between* sampling locations, where concentrations are unknown. In addition, as a three-dimensional object, it can be more difficult to judge the overall fit of a given map, especially when trying to assess residual error. It is also often true that high and low concentrations may be clustered together at nearby wells, perhaps due to lack of spatial continuity in concentration patterns, temporary 'spikes' in concentration at one of the wells, differences due to variation in well screen depth, or low hydraulic conductivity. Such situations make it difficult to minimize residual error regardless of bandwidth, and often necessitate user input to ensure a pleasing map. GTS has a built-in user interface for checking and, if necessary, overriding the default spatial bandwidths. Residuals are checked via color-coded post-plots of the relative errors.

Though these steps worked to ensure the general accuracy of GTS maps, as measured by relative residual error, some testers either criticized the base-maps as not well-matched to existing plume maps of their site or suggested improvements to the map-making features in GTS. At least three problems were evident:

- Given the need to create maps across an entire site area, there is no ‘spatial gap analysis’ similar to the trend ‘gap analysis.’ As such, inaccurate spatial trends may occur between wells in sparsely sampled areas.
- Maps are currently extended to the site boundaries for all aquifer zones, even if one or more zones are only sampled within a smaller portion of the site. This can lead to inaccurate spatial extrapolation of the concentration estimates.
- The visible contours on GTS maps are selected from a fixed set of concentration levels, as opposed to being selected by the user based on site-specific criteria or regulatory limits. This can lead to GTS maps appearing rather different from traditional hydrogeologic maps, even if the underlying estimated concentration patterns are substantially the same.

Overall, while the trends and maps in GTS do minimize residual error as per the stated performance objective, several improvements to the map-making facility could be implemented. This objective is therefore rated as partially met.

### 6.2.7 Versatility

The expected performance metric is that the upgraded and revised GTS software is able to perform optimization studies at sites with more than 200 wells. The purpose for this objective is to ensure that GTS can be used at larger facilities, in addition to smaller ones. The previous beta version of the software, GTS v0.6, had a memory limitation due to its Fortran underpinnings that prevented its successful application to larger sites; in particular, it would fail at any site with more than 200 wells. So the new technologies in GTS — especially the R statistical computing environment — were specifically selected to ensure that GTS would no longer have this limitation. Each of the demonstration sites for this project was also selected with this aspect in mind; all of the sites have more than 200 wells, ranging from 208 at AFP44 to 467 at Fernald. In each case, optimization analyses were successfully run, as documented in previous sections, with no memory limitations or difficulties. Based on this success, the performance objective is met.

### 6.2.8 Return on Investment (ROI)

The expected performance metric is that the annual cost savings realized from implementing a GTS-recommended optimal sampling plan will more than offset the expense of utilizing GTS and performing an optimization study. In fact, the expectation is that a return on investment (ROI) will occur within 3 years of implementation at most sites and at each of the demonstration sites. The purpose behind this objective is to ensure that GTS provides a cost-effective and resource-saving optimization strategy. This was evaluated by importing the optimization results generated by the ESTCP project team into the GTS cost comparison calculator. The calculator is designed to compute ROI as one of its final outputs, as discussed in **Section 2.3** and **Section 7.3**.

Calculation of ROI essentially weighs three components: 1) cost of performing the optimization study with GTS, including data retrieval, cleaning, and preparation, along with labor hours to run and interpret the software; 2) cost of installing and sampling any additional well locations proposed by GTS; and 3) yearly savings re-captured through reductions in sampling frequency and elimination of redundant wells from the monitoring network. As

mentioned earlier and detailed in **Section 7.3**, none of the independent site analysts completed or submitted the GTS cost comparison calculator spreadsheet. Further, the analysts were not asked to keep a detailed log of hours they spent running the software (this would have been difficult in any case given the overlap between the GTS development and demonstration phases as discussed in **Section 6.2.1**). In addition, while each site was responsible for gathering and submitting electronic data for the project, the ESTCP project team was responsible for data cleaning and preparation. As a consequence, reasonable assumptions had to be made concerning labor hours and rates to perform the optimization study. The ESTCP project team further decided which new well locations suggested in the network adequacy analysis should be reasonably included in the cost benefit calculations.

Using these assumptions, the estimated return on investment (ROI) or payback easily met the performance objective. At AFP44, the total cost of new wells and doing the optimization amounted to \$59K, less than the expected annual savings of \$191K, leading to an ROI of less than 4 months. For NOP, the total cost of new wells and optimization was approximately \$89K, compared to an annual savings of \$181K, or an ROI of roughly 6 months. At Fernald, the additional expense was \$49K versus an annual savings of \$162K, for an ROI of approximately 4 months. So this performance objective is clearly met, even if some of the assumptions made by the ESTCP project team as to optimization costs or numbers of new wells installed were different than what the site would choose in practice.

# 7.0 COST ASSESSMENT

This section addresses the costs and benefits of implementing GTS for LTMO at typical DoD and government sites, including the potential cost savings that might result. Most of the expected savings will be derived from reductions in sampling frequency, and more generally from the temporal and spatial redundancies that GTS identifies. Additional costs will be associated with the installation, maintenance, and sampling of any new wells suggested by the network adequacy analysis, along with costs of performing the optimization study. The net cost-benefit balance for the three demonstration sites is discussed below.

## 7.1 COST MODEL

The GTS software is publicly-funded open-source freeware. As such, any user can download and use GTS at any site, public or private, without charge. The software is also designed to run on standard Windows-based desktop computing environments, so no capital purchases are required. Therefore, the cost of implementation is the estimated cost of applying the software at a typical site, with possibly some minor training costs for initial use.

The GTS cost comparison calculator was designed to quantify and automate a simple, but realistic cost model for implementing GTS. The key cost elements associated with performing an optimization study are listed in **Table 7-1**. These include start-up costs for downloading, installing, and learning the software; data retrieval and preparation, including formatting for GTS import, data importing, and removal of outliers and COC selection once within GTS; optimization, both temporal and spatial, along with analysis of any new wells suggested by the network adequacy analysis; populating site-specific cost factors into the GTS cost comparison calculator and importing the optimization results; and periodically conducting trend flagging and/or plume flagging on newly collected data. Note that the cost calculator spreadsheet itself does not break out these elements in the same way as **Table 7-1**. Rather, standard labor categories are listed, with options for the user to set site-specific labor rates and number of hours expended in each category.

**Table 7-1. Estimated Costs to Apply GTS at a Typical Site**

| Cost Element | Estimated Level of Effort | Estimated Cost |
|---|---|---|
| Start-Up | | |
| Software Cost | Free | $0 |
| Software Download/Install | 1-2 hrs @ $100/hr | $200 |
| Training/Learning | 16 hrs @ $100/hr | $1600 |
| | **Subtotal** | $1800 |
| Data Preparation/Import (per site) | | |
| Data Retrieval/Prep | 40 hrs @ $100/hr | $4000 |
| Data Import | 2 hr @ $100/hr | $200 |
| Data Exploration/Massaging | 2-6 hrs @ $100/hr | $600 |
| | **Subtotal** | $4800 |
| Optimization (per site) | | |
| Temporal Optimization | 4-10 hrs @ $100/hr | $1000 |
| Spatial Optimization | 6-24 hrs @ $100/hr | $2400 |
| Network Adequacy | 2 hr @ $100/hr | $200 |
| Interpret Results/Write-up | 20 hrs @ $100/hr | $2000 |
| | **Subtotal** | $5600 |
| Cost-Benefit Analysis | | |
| Populate Cost Calculator | 1-2 hrs @ $100/hr | $200 |
| Import/Format Optimization Results | 1-2 hrs @ $100/hr | $200 |
| Write-up Results | 1 hr @ $100/hr | $100 |
| | **Subtotal** | $500 |
| Trend/Plume Flagging (Periodic) | | |
| Create GTS-ready file for New Data | 8 hrs @ $100/hr | $800 |
| Import Data and Run Trend/Plume Flagging | 1-2 hrs @ $100/hr | $200 |
| Export Reports, Write-up Results | 5 hrs @ $100/hr | $500 |
| | **Subtotal** | $1500 |
| **Optimization Study Total** | **110-142 hrs @ $100/hr** | **$14,200** |

## 7.2 COST DRIVERS

The cost estimates provided in **Table 7-1** are rough upper limit estimates based on the testing performed at the three demonstration sites as part of this project. Costs of applying GTS at typical DoD and government sites may vary, but should significantly exceed the estimates in **Table 7-1** only at very complex and very large facilities (e.g., thousands of wells, hundreds of potential COCs, more than five aquifer layers, etc.). Cost drivers that would potentially impact the cost of applying GTS would include:

- *Labor Mix and Computing Costs* — **Table 7-1** assumes that much of the effort in a typical optimization study will be conducted by mid-level and junior-level analysts. Thus, the assumption that labor rates will average $100 per hour across the project. Further, it is assumed that physical computational time will be billed in labor hours, and that multiple variations in optimization formulation/strategy may be attempted. Should the labor mix include a higher proportion of senior-level time, the cost structure may be higher. On the other hand, should optimization runs be conducted overnight with no labor charge attached to physical computing time, costs could be significantly less than those estimated above.

- *Quality and Format of Site Data* — Data preparation cost is highly dependent on the quality and existing format of the available historical data. During data preparation, site data are converted into ASCII text files that can be imported into GTS. This includes an analytical data input file, and also a water level file if those measurements exist. Obviously, the level of effort will depend on the format of the site data, and the extent to which site data have previously been screened for data quality. At many sites, historical analytical sampling data are already available electronically, and reformatting those data into the proper format for input into GTS is a straightforward exercise using software such as MS-Excel or a robust text editor.

  Nevertheless, since GTS also requires fields and field names consistent with the ERPMS data structure, some sites may need to reformat their data to fit ERPMS conventions. Further, if some site data are not in digital format, then those data may need to be converted into electronic format, which could substantially increase the data preparation cost. The estimate provided in **Table 7-1** of $4,000 for data preparation assumes the data are available electronically, allows for fairly detailed screening of the data for potential data quality issues, and assumes that only minor data quality issues will be discovered (e.g., inconsistent or missing well names and/or well coordinates; inconsistent aquifer designations; missing detection status [PARVQ]). If more substantial problems with data quality are found, data preparation costs could be higher.

- *Number of Distinct Sites and/or Aquifer Zones* — The three demonstration sites were analyzed as single, discrete areas (as encompassed by a single site boundary). AFP44 has essentially four aquifer layers, though one layer is too sparsely sampled to be reasonably analyzed by itself. NOP has three layers, and Fernald has one (based on initial data supplied to the ESTCP project team). Run times for GTS optimization

were thus based on these site configurations. Since each additional aquifer layer and/or discrete site area increases run times linearly, costs will be higher at installations with greater numbers of site-aquifer layer pairs.

- *Number of COCs* — Each COC optimized adds linearly to GTS run times. Since the maximum number of COCs that can be simultaneously analyzed is currently capped at four, and AFP44 was analyzed with this configuration, **Table 7-1** should accurately reflect the upper cost limit as it pertains to number of COCs. However, should a site choose to make multiple runs on more than four COCs, costs would be higher.
- *Number of Wells, Amount of Historical Data* — The number of wells in a data set adds greater than linear complexity to GTS optimization run times. At the demonstration sites, the maximum number of wells analyzed was 467 (376 unprotected and eligible for optimization). Sites with larger numbers of wells will incur more run time and hence higher cost. The length of the historical data record at each well impacts temporal optimization run times using iterative thinning. Sites with extensive histories will incur the longest run times. Since there were numerous wells at the demonstration sites with 15-20 year histories, run times may not be much longer than **Table 7-1** for the majority of prospective facilities.

## 7.3 COST ANALYSIS

A cost-benefit analysis for applying GTS as an LTMO tool must account for the costs of doing an optimization study, the costs of any new wells added as a result of the study, and cost savings likely to be realized from identifying and eliminating redundancy. The estimated costs of performing an optimization study are presented in **Table 7-1**. The GTS cost comparison calculator is designed to balance these costs against the other two components: 1) cost of new wells, and 2) cost savings from eliminating redundancy in sampling and analysis.

Actual costs and savings are subject to many site-specific factors such as the number of aquifers, numbers of wells and contaminants, cost of sampling and laboratory analysis, labor rates, and several other factors. Since these factors vary from site to site, a definitive cost analysis cannot be provided. However, it is possible to describe the factors and assumptions incorporated into the GTS cost comparison calculator and illustrate the cost analysis derived for each of the three demonstration sites.

An annual cost summary using the GTS cost comparison calculator is built from the following elements and assumptions:

- *Input of the GTS optimized network status report*. This text file includes all of the distinct baseline wells used in the analysis, their baseline and optimized sampling frequencies, and which wells were deemed redundant.
- *Analytes or analyte groups and their relative frequency of sampling*. Users are asked to input each analyte or group of analytes being monitored (e.g., metals by analytical method), as well as the laboratory analysis cost per sample for each one. Users can also input a relative frequency factor between 0 and 1 for each analyte (default = 1) to indicate those contaminants or groups that are sampled either less often than the analyte sampled most frequently (e.g., metals sampled quarterly, VOCs sampled

semi-annually), or that are sampled in only a portion of the site (e.g., wells in lower southwest quadrant).

- *Optimal sampling frequencies*. Although the cost comparison calculator automatically inputs optimized sampling frequencies from the optimized network status report file, users can choose to employ either a site-wide frequency, aquifer zone-specific frequencies, or well-specific frequencies, depending on which type best fits the operational profile and configuration of the site. Well-specific frequencies delineate an optimal sampling frequency for each and every well, but also then require well-specific sampling schedules. Often, operational constraints dictate a single sampling frequency for the site as a whole (site-wide), or perhaps for each aquifer (aquifer zone-specific).

- *Suggested new wells and their proposed sampling frequencies*. Users are asked to input a text file listing the number and coordinates of all new well locations. This file is exported from the GTS application as the new well location report. Each new location can be assigned its own sampling frequency, generally either the optimal site-wide frequency or an aquifer zone-specific value.

- *Costs to install new wells*. Common industry default unit costs are provided for mobilization/demobilization, monitoring well installation per foot of depth, dedicated pump, well survey, and well development. Users can override any of these defaults, including the average depth of drilling, in order to build a realistic, site-specific cost structure.

- *Quality control samples*. A default rate of 20% is used to compute the number of field QC samples to be collected each year for each analyte or analyte group. The user can override with a site-specific rate if desired. The QC samples are added to the number of samples per year collected from both essential wells and new well locations to derive a total number of samples per year per analyte and their associated analytical cost.

- *Labor rates*. Default hourly rates are provided for senior level, mid level, junior level, and technician. Users can override these rates with site-specific values.

- *Field sampling costs*. Default values are provided for the number of hours typically spent annually per well to do field sampling for each labor category (e.g., 0.1 hour for senior level, 3 hours for technician). Total field sampling costs are built up from the labor rates per hour and the number of wells sampled per year.

- *Other labor costs*. Default values are given for number of hours by labor category spent on chemistry data management (users can override). Similar input slots are also provided for typical hours spent on reports and meetings, as well as project management, administration, and QA. GTS assumes that reports, meetings, and project management costs are essentially constant regardless of whether an optimized sampling program is adopted.

- *Non-labor costs*. Default values are provided for sample shipping costs and sampling equipment and materials on a unit basis. Users can override defaults for samples per

cooler and shipping cost per cooler, as well as those for materials and/or equipment per well.

- *Optimization study costs*. Users can input hours by labor category necessary to run a GTS optimization study. They can also input others costs, such as site visits, photocopies, etc.
- *Cost Summary*. All unit costs are escalated to compute both a baseline (i.e., current) cost summary (including all analytical and sampling costs) using the current well network and sampling frequencies, and an optimized cost summary using both the essential wells and the newly proposed well locations, coupled with the GTS-optimized sampling frequencies. The overall annual net balance is derived by adding the costs of the baseline monitoring program to the costs of the optimization study, and then subtracting the costs of the proposed optimized monitoring program.

The GTS cost comparison calculator was applied to each of the three demonstration sites for this project, based on the optimization analyses conducted by the ESTCP project team. Because detailed information on all the cost elements could not be obtained from every site, default values and assumptions were utilized to 'fill in the gaps.' Thus, the cost summaries presented below should be regarded as hopefully reasonable estimates, but not actual dollar amounts. It should also be noted that contractors working at AFP44 did review the GTS cost comparison calculator and provided some site-specific cost data for that installation. They noted that the defaults utilized in the calculator were quite similar to their own cost structure.

**AFP44 Estimated Cost Analysis**

Use of the GTS cost comparison calculator at AFP44 (**Figure 7-1**) involved the following site configuration and assumptions:

- 208 wells in the baseline monitoring program were analyzed, 2 of which were designated as protected based on recommendation of site representatives. Within this network, a suite of volatile organic chemicals (VOCs) was regularly and extensively sampled, including two contaminant drivers — TCE and 1,1-DCE. Two other COCs, total chromium and 1,4-Dioxane, were sampled either less often or only across a portion of the network. These last two contaminants were given fractional relative sampling rates for purposes of the cost analysis (chromium = 0.5, 1,4-Dioxane = 0.25). All four of the COCs — TCE, 1,1-DCE, chromium, and 1,4-Dioxane — were optimized using GTS. Analytical costs per sample were estimated by SAIC and then confirmed by AFP44 site representatives, amounting to $25 per chromium sample, $150 per 1,4-Dioxane sample, $90 for TCE and 1,1-DCE, and $115 for other VOCs. A rate of 20% for field QC sampling was also assumed.
- Three semi-distinct aquifer zones were optimized, representing a deeper layer (LZ-UZLU), an upper layer (UZUU), and a topmost layer present over a portion of the site (SGZ). Optimal sampling frequencies were computed with iterative thinning. By aquifer zone, the optimized number of annual samples per well was computed equal to 1 for wells in the LZ-UZLU and SGZ layers, and 0.8 for wells in the UZUU layer.

- Based on version 2 of the AFP44 database, 155 wells were deemed essential and thus part of the optimal sampling network. For purposes of costing the optimal program, aquifer zone-specific optimal sampling frequencies were selected.
- Six of 20 new well locations were retained from the network adequacy analysis. Those eliminated were either very close to existing wells or located in areas where the SGZ aquifer zone did not extend. The same aquifer zone-specific sampling frequencies were applied to these proposed wells. Default values were assumed for new well installation costs, amounting to $9,000 per well.
- Labor rates by category were supplied by AFP44 representatives, along with unit labor costs for field sampling, chemistry data management, and administrative hours. Reports, meetings, and project management hours were assumed to be constant regardless of optimization.

**Figure 7-1. AFP44 Cost Analysis Summary**

**Summary**

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| AFP44-2 | Baseline Program | Optimized Program |
|---|---|---|
| **Wells Monitored Per Year** | **208** | **161** |
| **Average Sampling Frequency (per well, per year)** | **3.0** | **1.0** |
| **Annual Costs** | | |
| Sample Analysis | $ 189,080 | $ 48,125 |
| Field Sampling Labor | $ 104,146 | $ 80,613 |
| Sample Shipping | $ 12,750 | $ 3,250 |
| Sampling Materials and Equipment | $ 11,440 | $ 8,525 |
| Chemistry Data Management | $ 18,422 | $ 4,680 |
| Reports and Meetings | $ 80,400 | $ 80,400 |
| Project Management, Administration, and QA | $ 17,664 | $ 17,664 |
| **Total Annual Program Cost** | **$ 433,902** | **$ 243,257** |
| **Potential Annual Cost Savings** | | **$ 190,645** |
| **Percentage Reduction from Baseline** | | **43.94%** |
| | | |
| **Return on Investment (Payback) Analysis** | | |
| Cost of New Well Installation | | $ 45,000 |
| Cost of Optimization Analysis | | $ 13,835 |
| **Total Investment** | | **$ 58,835** |
| **Optimization will pay for itself in less than:** | | **4 months** |

The cost analysis at AFP44 suggests that almost 44% of the baseline monitoring program cost might be eliminated by adopting the GTS optimized sampling plan, or an approximate total of $191K per year. Less savings would be realized in any year in which an optimization study was conducted and/or new wells were installed. Assuming this study was conducted at the start of the first year of a multi-year monitoring horizon, the net savings for the first year would amount to roughly $132K, after installing 6 new wells and paying for the study. Still, the estimated return on investment (ROI) is less than 4 months.

**NOP Estimated Cost Analysis**

Use of the GTS cost comparison calculator at NOP (**Figure 7-2**) involved the following site configuration and assumptions:

- 250 wells in the baseline monitoring program were analyzed, 77 of which were designated as protected by directive of site representatives. Within this network, a suite of volatile organic chemicals (VOCs) is regularly and extensively sampled, including one contaminant driver, TCE. Another suite of explosives, including COC RDX, is also regularly sampled. The two COCs, TCE and RDX, were optimized as part of the demonstration. Analytical costs per sample were initially estimated by SAIC but then slightly revised by NOP site representatives. These amounted to $100 per VOC sample and $250 per explosives sample. A rate of 20% for field QC sampling was assumed.
- Three distinct aquifers were optimized, representing SHALLOW, MEDIUM, and DEEP layers. Optimal sampling frequencies were computed with iterative thinning. By aquifer zone, the optimized number of annual samples per well was computed as 1 for wells in the MEDIUM and DEEP layers, and 1.33 for wells in the SHALLOW layer.
- Including the 77 protected locations, 222 wells were deemed essential and thus part of the optimal sampling network. For purposes of costing the optimal program, aquifer zone-specific optimal sampling frequencies were selected.
- Ten of 14 new well locations were retained from the network adequacy analysis. Those eliminated were very close to existing wells. The same aquifer zone-specific sampling frequencies were applied to these proposed wells. Default values were assumed for new well installation costs, amounting to $7,500 per well.
- Default labor rates by category were utilized, along with default unit labor costs for field sampling, chemistry data management, and administrative hours. Reports, meetings, and project management hours were assumed to be constant regardless of optimization.

**Figure 7-2. NOP Estimated Cost Summary**

**Summary**

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| NOP Cost Summary | | | | |
|---|---|---|---|---|
| | Baseline Program | | Optimized Program | |
| **Wells Monitored Per Year** | | **250** | | **232** |
| **Average Sampling Frequency (per well, per year)** | | **2.6** | | **1.1** |
| **Annual Costs** | | | | |
| Sample Analysis | $ | 272,650 | $ | 111,300 |
| Field Sampling Labor | $ | 80,000 | $ | 74,240 |
| Sample Shipping | $ | 9,750 | $ | 4,000 |
| Sampling Materials and Equipment | $ | 13,750 | $ | 12,210 |
| Chemistry Data Management | $ | 10,322 | $ | 4,214 |
| Reports and Meetings | $ | 64,300 | $ | 64,300 |
| Project Management, Administration, and QA | $ | 14,640 | $ | 14,640 |
| **Total Annual Program Cost** | **$** | **465,412** | **$** | **284,904** |
| **Potential Annual Cost Savings** | | | **$** | **180,508** |
| **Percentage Reduction from Baseline** | | | | **38.78%** |

| Return on Investment (Payback) Analysis | | |
|---|---|---|
| Cost of New Well Installation | $ | 75,000 |
| Cost of Optimization Analysis | $ | 13,500 |
| **Total Investment** | **$** | **88,500** |
| **Optimization will pay for itself in less than:** | **6 months** | |

The cost analysis at NOP suggests that almost 39% of the baseline monitoring program cost might be eliminated by adopting the GTS optimized sampling plan, or an approximate total of $180K per year. Most of the savings is realized through reduction in sampling frequencies. Less savings would be realized in any year in which an optimization study was conducted and/or new wells were installed. Assuming this study was conducted at the start of the first year of a multi-year monitoring horizon, the net savings for the first year would amount to roughly $92K, after installing 10 new wells and paying for the study. The estimated return on investment (ROI) is less than 6 months.

### Fernald Estimated Cost Analysis

Use of the GTS cost comparison calculator at Fernald (**Figure 7-3**) involved the following site configuration and assumptions:

- At least some historical data existed for 467 wells and DPT locations in the baseline monitoring program. Of these, 91 were designated as protected because they had recently been abandoned but were still part of the database. To ensure that these abandoned locations were not included as part of either the current baseline or optimized sampling programs, all 91 were manually removed from the GTS optimized network status report prior to importing into the GTS cost comparison calculator. This left 376 active locations as part of the baseline monitoring program. Within the current network, the single contaminant driver and COC was uranium.

Analytical costs per sample were estimated by SAIC at $75 per sample. A rate of 20% for field QC sampling was assumed.

- Although uranium was the only COC at Fernald and the only contaminant assessed in the cost analysis, the historical database contained a few other contaminants sampled sporadically at a much more limited subset of well locations. Including these contaminants in the cost analysis would tend to increase the overall cost savings, but has not been estimated in **Figure 7-3**.
- Based on the data that was initially provided to the ESTCP project team, all locations at Fernald were analyzed as if part of a single aquifer (2D analysis). Optimal sampling frequencies were computed with iterative thinning. The optimized number of annual samples per well was computed as 1.33.
- 231 active wells and DPT locations were deemed essential and thus part of the optimal sampling network. For purposes of costing the optimal program, a site-wide optimal sampling frequency was selected.
- 4 new well locations were retained from the network adequacy analysis. The same site-wide sampling frequency was applied to these proposed wells. Default values were assumed for new well installation costs, amounting to almost $9,000 per well.
- Default labor rates by category were utilized, along with default unit labor costs for field sampling, chemistry data management, and administrative hours. Reports, meetings, and project management hours were assumed to be constant regardless of optimization.

**Figure 7-3. Fernald Estimated Cost Analysis**

## Summary

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| Fernald | Baseline Program | Optimized Program |
|---|---|---|
| **Wells Monitored Per Year** | **376** | **231** |
| **Average Sampling Frequency (per well, per year)** | **3.5** | **1.3** |
| **Annual Costs** | | |
| Sample Analysis | $ 119,475 | $ 27,750 |
| Field Sampling Labor | $ 120,320 | $ 73,920 |
| Sample Shipping | $ 10,000 | $ 2,350 |
| Sampling Materials and Equipment | $ 20,680 | $ 12,485 |
| Chemistry Data Management | $ 10,554 | $ 2,451 |
| Reports and Meetings | $ 64,300 | $ 64,300 |
| Project Management, Administration, and QA | $ 14,640 | $ 14,640 |
| **Total Annual Program Cost** | **$ 359,969** | **$ 197,896** |
| **Potential Annual Cost Savings** | | **$ 162,072** |
| **Percentage Reduction from Baseline** | | **45.02%** |
| | | |
| **Return on Investment (Payback) Analysis** | | |
| Cost of New Well Installation | | $ 35,000 |
| Cost of Optimization Analysis | | $ 13,568 |
| **Total Investment** | | **$ 48,568** |
| **Optimization will pay for itself in less than:** | | **4 months** |

The cost analysis at Fernald suggests that 45% of the baseline monitoring program cost might be eliminated by adopting the GTS optimized sampling plan, or an approximate total of $162K per year. Savings are realized both through reduction in sampling frequencies and elimination of redundant wells. Less savings would be realized in any year in which an optimization study was conducted and/or new wells were installed. Assuming this study was conducted at the start of the first year of a multi-year monitoring horizon, the net savings for the first year would amount to roughly $113K, after installing 4 new wells and paying for the study. The estimated return on investment (ROI) is less than 4 months.

# 8.0 IMPLEMENTATION ISSUES

This section discusses issues related to future implementation of the GTS software technology at prospective sites. Relevant issues discussed below include:

- Software availability and documentation
- Ease of use
- Limitations of GTS v1.0
- Proposed and recommended changes to the software
- Regulatory issues

**Software Availability and Documentation**

The anticipated end-users of GTS include both government personnel and support contractors managing groundwater monitoring programs, whether at public or private facilities. A copy of the software executable, GTS cost comparison calculator spreadsheet, and users guide will be made available on the AFCEE website. Sample input data files — pre-formatted according to GTS specifications — will also be available at the website.

Anyone with legal access to the AFCEE website can download and install GTS for free onto their desktop computer. As publicly-funded, open source freeware, there are no restrictions on GTS usage, nor does a license need to be secured or purchased. The software and users guide were previously submitted as a separate deliverable under this ESTCP project.

Although the software and its usage are free, there is no technical support or training available for GTS at this time. Such support and/or training can be purchased separately from MacStat Consulting, Ltd. (send request to kcmacstat@qwest.net).

**Ease of Use**

Overall, the GTS software was found to be easy to use by the testers and mid-level site analysts. None of these users was formally trained on the software; questions regarding usage (and other project matters, including software bugs and development) were fielded in weekly conference calls sponsored by the ESTCP project team. Experience with other LTMO software varied among the testers; most had some previous experience running MAROS. Users commented that:

> "This tester rates the general usability of GTS as very good considering it is in beta form. Its modular structure is logical and relatively easy for the minimally experienced geostatistical practitioner to use."

> "The five major modules coupled with Windows menu and dialog boxes allow an environmental professional with limited statistical training and expertise to navigate successfully through the many spatial and temporal elements of GTS.

The graphical user interface (GUI) appears to be highly functional and user friendly."

"The software is quite user-friendly. The screens are easy to navigate and read. The screen sequence is logical and appears to be structured to prevent a novice user from bypassing necessary steps. On the other hand, the ability to jump to other steps that have either already been conducted or that can be conducted based on the steps already completed make the program easy to navigate."

"Apart from bugs encountered during the Fernald application, GTS was easily used. The interface made sense and was clear."

"The overall ease of use is good, as familiarity with the 5 main modules and their underlying windows comes fairly quickly."

**Limitations of GTS v1.0**

GTS v1.0 has certain limitations that will impact its use at prospective sites. Many of these concerns/limitations have been mentioned earlier in this report, but are listed here for completeness:

- *Data Importing* — GTS requires input of a large number of data fields, though users have not always been clear on which fields are required vs. optional. In addition, the data fields must be named and formatted according to ERPIMS-consistent conventions. Some users suggested that the importing process could be simplified and better explained.
- *Exporting Graphics* — GTS is predicated on significant graphical analysis of data and generates a large number of statistical graphics when applied at medium to larger sites. Yet there is no current feature allowing for easy export of batches of related plots/maps. Instead users must capture screen shots of individual graphics they would like to save and import into other documents or software. In addition, GTS maps are static images and not configured for import into GIS software.
- *Map Displays* — Users commented that "maps created by GTS do not always have consistent spacing along the easting and northing axes, leading to distorted views." Users also mentioned lack of control over colors, symbols, fill patterns, and contours. Inability to contour areas of regulatory exceedance was cited as a reason for GTS base-maps looking different and inferior to traditional plume maps, along with the coarse default grid over which GTS computes map estimates.
- *Compatibility* — GTS was designed to be fully compatible with desktop systems running Windows XP. However, the architecture was finalized prior to the adoption of either Windows Vista or Windows 7. Some users expressed difficulties in getting GTS properly loaded and running on Vista or Windows 7 systems, especially with 64-bit machines, although others seemed to have little difficulty.
- *Optimization Runtimes* — At large sites (> 200 wells), optimization runs — using iterative thinning or especially GTSmart — may take several hours to complete

(perhaps necessitating overnight runs). This is a limitation for users needing to complete a project on a tight deadline or for those who want to test out several variations of parameter choices and/or data configurations.

- *Technical Guidance* — Multiple users commented that since the current users guide does not include any technical appendices, they were sometimes unsure of what GTS was doing or computing at particular steps, or that they were unsure how to interpret GTS results (e.g., why were certain wells flagged as redundant but not others; how to select and interpret temporal and spatial bandwidths).
- *Minimum Data Requirements* — Effective spatial optimization in GTS requires a minimum of 15-20 wells and at least two sampling events per well; temporal optimization requires at least 1 well and 6-8 distinct sampling events per location.
- *Radiochemical Data* — GTS does not offer sophisticated handling of radiochemical data, particularly measurements recorded with non-positive values (i.e., zeros or negatives). These data must first be converted to positive values, unless they represent non-detects with a known, positive detection or reporting limit.
- *Temporal Optimization* — Optimized sampling intervals from temporal variograms in GTS often do not match the optimized sampling intervals from iterative thinning using the same data. Further improvements to the temporal variogram algorithm may be needed, especially to account for sites with spatial trends that are actively changing over time.
- *Cost-Accuracy Tradeoffs* — Cost-accuracy tradeoff curves in GTS are not interactive. Although the bias limits can be adjusted by the user, the spatial optimization must be completely re-run each time those limits are changed, in order to see the impact of the revised limits and to generate a new optimal network.
- *Plume Mass* — GTS v1.0 does not track changes in contaminant or plume mass, nor does it allow users to specify contaminant mass as an optimization criterion.

**Proposed and Recommended Changes to the Software**

Based on the limitations of the current v1.0 release of GTS, along with additional user feedback, several changes are proposed for a future v2.0 release in order to increase its ease of use, flexibility, and adaptability to real-life environments and 'messy' data sets. These include the following items:

- **System-wide Upgrades**
    - Make GTS fully compatible with Windows 7.
    - Graphical User Interface (GUI) — Add menus to provide direct access to GTS features/components. Allow users to set preferences and options.
    - Add context-sensitive user help throughout GTS.
    - Restructure the GUI to more easily allow users to perform *only* a temporal optimization if a site has less than 15 wells, or *only* a spatial optimization if there are fewer than 6-8 separate sampling events.

- Improve sorting and display of SQLite Database tables (these house data imported into GTS).
- Improve sorting and display of GTS analysis reports.
- Improve user navigation and searching through batches of GTS plots. A typical GTS analysis generates a large volume of plots that the user may desire to electronically save and/or print for use outside the application. Add ability to save/print graphics from GTS output, including automated batches of graphics when desired. Allow users the option to export GTS graphics as JPEG or similarly-formatted electronic files.
- Graphics — add more user-control over graph options and appearance; improve display of maps and shape file map overlays; expand interactivity between paired graphs and tables (e.g., if user clicks on a well in a post-plot, highlight that well in the associated table).
- Users Guide — expand to include technical appendices and additional material on how to judge and interpret GTS optimization results.

- **Module A (Prepare) Upgrades**
  - Expand checks for inconsistent or missing data, such as dilution 'outliers,' unusual lab qualifiers, inconsistent elevations/depths, duplicate records, etc.
  - Improve computation and display of GTS 'time slices' (i.e., time 'snapshots' used to subset data for analysis); allow users to manually adjust time slice ranges, in order to account for site-specific changes to the monitoring program (e.g., installation of new treatment system).
  - Improve display and documentation of data import capability. Streamline and improve user interface for data import, making it easier for users to navigate the import process.
  - Improve display of well post-plots, including addition of separate plots by vertical zone.
  - Restrict spatial mapping and display to expanded convex hull around existing well locations.
  - Outliers — combine current temporal and spatial outlier searches into one; simplify GTS interface for identifying and confirming suspected outliers; perform outlier searches separately by vertical zone for each contaminant of concern (COC).
- **Module B (Explore) Upgrades**
  - Improve GTS interface for displaying data summary statistics.
  - Display post-plots of concentration levels and MCL exceedances by vertical zone.
  - Improve vertical horizon analysis; check for consistency of vertical zone designations; improve display of current box plots.

- **Module C (Baseline) Upgrades**
    - Sampling gaps — improve ease of use by eliminating current ‘sampling gaps’ diagnostic interface. Revise trend-fitting algorithms to better account for large sampling gaps.
    - Improve usability of table of trend types and ‘Check Bandwidths’ interface.
    - Improve display of baseline trends; link each trend with a displayed numeric table of trend results; hot-link locations on each trend map with their associated baseline trends.
    - Spatial Bandwidth interface — Improve user ability to select appropriate bandwidth parameters by adding new diagnostic plots and improving existing display of map residuals.
    - Improve display of base-maps and existing color bar legends; expanding viewing options to improve handling of highly skewed data.
    - Test and deploy water-flow aided spatial mapping; GTS does not require numerical flow and transport models, yet will provide improved spatial mapping by *combining* information about the potentiometric surface along with observed patterns of contaminant levels. Install as an additional user option for data sets that include water level measurements.
- **Module D (Optimize) Upgrades**
    - Temporal variograms — improve computation and accuracy by a) enabling option to compute variograms on transformed data (e.g., log, square root); test option of computing variograms on de-trended data, using baseline trend to de-trend each COC-well pair.
    - Improve display of iterative thinning optimization results by adding graphic that overlays baseline trend, optimized trend, and confidence band utilized in the thinning algorithm
    - Temporal optimization — revise iterative thinning algorithm to allow optimization of both Theil-Sen and LWQR trends; as part of this change, perform exhaustive thinning on small data sets ($n \leq 10$) to expand flexibility and improve accuracy of iterative thinning technique
    - Spatial optimization — Current GTSmart optimization strategy is a quasi-genetic algorithm. Improve by developing and deploying a full genetic algorithm that retains the computational benefits of GTSmart. This will improve the accuracy and defensibility of GTS spatial optimization results.
    - Add option for user to separately optimize water level data if available. This will allow for more efficient potentiometric surface mapping.
    - Increase flexibility by adding option for user to pick alternative critical index threshold by which GTS delineates critical versus redundant well locations.
    - Tradeoff curves — develop and test option of combining current tradeoff curves into single, weighted curve for use in determining point(s) of optimality; link

points on tradeoff curve to specific sampling plans; this will allow user to compare different possible optimal plans without having to re-run entire optimization routine.

- Improve display of spatial optimization results by adding a graphical and tabular summary of the numbers of essential/redundant wells by vertical zone.
- Cost Comparison Calculator — Integrate current cost calculator Excel spreadsheet into GTS interface. This will allow seamless computation of optimization benefits from within the GTS application, instead of user having to export results and then import into a separate spreadsheet in Excel.

- **Module E (Predict) Upgrades**
  - Trend anomalies — improve current prediction band used to flag potential anomalies by revising code to add a 'flat' linear extension. This will cover cases where the apparent trend has recently 'flattened out' instead of continuing a past rise or descent.
  - Improve display of trend anomalies by hot-linking the time series plots which currently display prediction bands to locations graphed on the trend anomalies post-plot (i.e., if a user clicks on a particular location, the hot-linked time series plot would then display).
  - Improve display and usefulness of uncertainty envelopes by expanding viewing options to include either log-scale or concentration-scale displays.
  - Hot-link well-specific time series plots also to locations displayed on plume anomalies post-plot. This will allow user to gain longitudinal perspective on potential plume anomalies.

**Regulatory Issues**

Regulatory approval of a GTS-optimized sampling plan typically boils down to three concerns: 1) is there an existing general consensus among stakeholders that sampling redundancy might be present and a regulatory willingness to consider alternate approaches? 2) will removing wells and/or sampling events from regular monitoring preclude obtaining data needed for remedial decision-making or site characterization? 3) how can GTS plume/site maps be trusted if they don't look like traditional hydrogeologic maps?

Interaction with regulators regarding implementing the GTS results at the three demonstration sites was not a specific part of this ESTCP project. However, each site was interested in evaluating the optimization results to determine whether changes would be justified in its sampling program. Preliminary findings of the optimization study were also presented to joint meetings of regulators and site personnel at AFP44. Both in that presentation and in talks given to other (non-ESTCP) sites, site personnel have generally been very receptive to GTS as an LTMO tool and have desired to use GTS results as a 'line of evidence' in regulatory discussions/negotiations.

Obtaining regulatory acceptance of GTS will probably require two major steps: 1) increasing awareness of LTMO in general, and awareness of GTS v1.0 in particular, within the regulatory community; and 2) individual sites agreeing to petition regulators for modifying their

LTM program based on a GTS-optimized sampling plan. As discussed in the section on current limitations above, there may also be a need to improve the mapping tools within GTS, so that users can set site-specific contours for visualizing areas of regulatory exceedance, and so that ‘hot spots’ are mapped more accurately.

To achieve the first step, AFCEE is actively promoting and advertising GTS as an available software tool. Efforts are also underway to develop an IRTC project that will spotlight GTS under the larger umbrella of analyzing groundwater monitoring data and meeting groundwater regulatory requirements.

With respect to the second step, each of the demonstration sites indicated they would be reviewing the GTS results to determine applicability and usability of the recommendations. AFP44 contractors indicated they would like to perform further analysis on their own, using the software, before presenting results to regulators in the form of a revised LTM plan. This was because they wanted to include site-specific factors not available to the ESTCP project team. Also, given the three-year schedule of this ESTCP project and the fact that the most recent year’s worth of data at each site was reserved for validation and testing of the trend/plume flagging features, the demonstration sites would be advised to repeat the optimization analysis using up-to-date data before incorporating the results into a revised LTM sampling plan proposal.

Improving the mapping capabilities in GTS will require an upgrade to the existing version. Efforts are underway to secure funding for such improvements.

# 9.0 REFERENCES


[1] RPO Inventory and Performance Software [RIPS], Air Force RPO Outreach Office

[2] DoD (2006) *Defense Environmental Programs Fiscal Year 2005 Annual Report to Congress*. Office of the Deputy Under Secretary of Defense, Washington, D.C.

[3] Cameron K (2004) Better optimization of LTM networks. *Bioremediation Journal*, 8 (03-04), 89-108

[4] Loader C (1999) *Local Regression and Likelihood*. New York: Springer-Verlag

[5] Goovaerts P (1997) *Geostatistics for Natural Resources Evaluation*. Oxford University Press, New York

[6] Cameron K & Hunter P (2002) Using spatial models and kriging techniques to optimize long-term ground-water monitoring networks: a case study. *Environmetrics*, 13, 629-656

[7] Cameron K (1999) Optimization of long-term monitoring networks: a statistical approach. Conference on Subsurface Remediation: Improving Long-Term Monitoring & Remedial Systems Performance, St. Louis, MO

[8] Cameron K & Hunter P (2000) Optimization of LTM networks: statistical approaches to spatial and temporal redundancy. Spring National Meeting of American Institute of Chemical Engineers, Atlanta, GA

[9] Cameron K (2002) Geostatistical optimization at AFP06 using GTS. 2002 AFCEE Technology Transfer Workshop, San Antonio, TX

[10] Cameron K (2003) Optimization at AFP06 using improved GTS. 2003 AFCEE Technology Transfer Workshop, San Antonio, TX

[11] Cameron KM & Hunter P (2003) Optimization of LTM networks at AF Plant 6 using GTS. In V.S. Magar & M.E. Kelley (Eds.), *In Situ and On-Site Bioremediation — 2003*. Proceedings of the Seventh International In Situ and On-Site Bioremediation Symposium (Orlando, FL; June 2003). ISBN 1-57477-139-6, Columbus, OH: Battelle Press

[12] Cameron K & Hunter P (2004) Optimizing LTM networks with GTS: three new case studies. Conference on Accelerating Site Closeout, Improving Performance, and Reducing Costs Through Optimization, Dallas, TX

[13] Cameron K (2006) Optimizing LTM networks: applying GTS at Tinker AFB. World Environmental & Water Resources Congress, Omaha, NE

[14] USEPA (2005) *Roadmap to long-term monitoring optimization*, Office of Superfund Remediation and Technology Innovation (5102G), EPA 542-R-05-003

[15] Minsker B (2003) *Long-Term Groundwater Monitoring: The State of the Art*, ASCE/EWRI Task Committee Report. American Society of Civil Engineers: Reston, VA

[16] Yamamoto JK (2000) An alternative measure of the reliability of ordinary kriging systems. *Mathematical Geology*, 32(4): 489-509

[17] Stewart R, Doley T, & Hunter P (2004) Estimating cost savings from the optimization of long term monitoring programs at U.S. Air Force bases. Conference on Accelerating Site Closeout, Improving Performance, and Reducing Costs Through Optimization, Dallas, TX

[18] Herrera GS, & Pinder GF (1998) Cost-effective groundwater quality sampling network design.

*Proc. XII International Conference on Computational Methods in Water Resources, Vol. I*, Crete

[19] Rizzo DM, Dougherty DE, & Yu M (2000) An adaptive monitoring and operations system (aLTMOs) for environmental management. In *Building Partnerships, Proc. 2000*, ASCE Joint Conference on Water Resources Engineering and Water Resources Planning & Management, R.H. Hotchkiss and M. Glade (eds.), American Society of Civil Engineers, Reston, VA, CD-ROM (ISBN 0-7844-0517-4)

[20] Deschaine LM (2003) Simulation and optimization of large scale subsurface environmental impacts; investigations, remedial design and long term monitoring. *Mathematical Machines and Systems*, National Academy of Sciences of Ukraine, No. 3,4: 201-218

# APPENDICES

## Appendix A. Points of Contact

| POINT OF CONTACT<br>Name | ORGANIZATION<br>Name<br>Address | Phone<br>Fax<br>E-mail | Role in Project |
|---|---|---|---|
| Philip Hunter, P.G. | AFCEE/TDV Hunter<br>2261 Hughes Ave, Ste 155<br>Lackland AFB, TX 78236-9853 | (210) 395-8441<br><br>philip.hunter@us.af.mil | Principal Investigator |
| Robert B. Stewart | SAIC<br>8301 Greensboro Dr<br>McLean VA 22102 | (703) 676-6965<br>(703) 736-0815<br>robert.b.stewart@saic.com | SAIC Project Manager |
| Michael Kenny | SAIC<br>1901 S 1st St, Ste D-1<br>Champaign, Il 61820 | (217) 337-9520<br><br>michael.j.kenny@saic.com | Lead Computer Scientist |
| Kirk Cameron, Ph.D. | MacStat Consulting<br>10330 Mill Creek Ct<br>Colorado Springs, CO 80908 | (719) 532-0453<br>(719) 532-0453<br>kcmacstat@qwest.net | Lead Statistical Scientist; R Programmer |
| Dave Becker, P.G. | USACE Environmental & Munitions Center of Expertise<br>1616 Capitol Ave, Ste 9200<br>Omaha, NE 68102-9200 | (402) 697-2655<br><br>dave.j.becker@usace.army.mil | Government Partner; GTS Tester |

# Appendix B. Air Force Plant 44 Optimization Results

This appendix includes the GTS optimization results computed by the ESTCP project team, as well as the summary reports (but not the attachments) submitted by the two independent site analysts. At AFP44, as noted in **Section 5.1**, two versions of the database were analyzed, differing only in how certain wells were categorized as to aquifer zone. Both sets of optimization results are presented below.

## AFP44 INDEPENDENT ANALYST SUMMARY REPORTS

### GTS Analysis of AFP44, AFCEE Analysis, Analyst #1

Software Usability

- Flow of operation is logical and straightforward, much like reading a book, left to right and down
- Data import is very involved and could be simplified; this is the single issue that could limit application to a wide audience
- User interface and navigation is simple; could be visually enhanced with more color and slick graphics but this is not a priority
- Reporting, in particular, the numerous graphics generated as output should be wholesale exported into a file for viewing and analysis; not sure what format would be best or universal
- Reports are good; perhaps minor tweaks on titles and descriptive info could be achieved
- Bugs appear to be largely worked out and controlled; suggest providing a list of all known issues/bugs/format nuances that are known to complicate or hinder running the software and highlight for user
- Improvements include exporting graphics for quick scan and review; format would allow import into Powerpoint or similar software
    - Consider MNA applications for analyzing performance monitoring data
    - Background metals analysis
    - Criteria for identifying outliers could be relaxed; having more than 10 pages of outliers seems excessive----but perhaps it is justified; could have the default to include outliers unless otherwise directed; perhaps use a rule of thumb in addition to box plot far-outside scenarios
    - Criteria to identify anomalies may be too sensitive; many of the flagged values when viewed in time series seemed reasonable and didn't merit attention in the context of flagrant violation of prediction bands

Case Study Report

- Electronic files, project files, and Powerpoint file of screenshots are attached
- Three separate optimizations were performed: 1) 2.5D, 3x horizons, merging UZLU and LZ, SGZ, and UZUU; all defaults accepted, 2) 2D, all defaults accepted, and 3) 2.5D, no merging of horizons, all defaults accepted
- Summary table attached below (includes comparative results from Analyst #2)

**Air Force Plant 44 GTS Analysis**

| Operator | Horizons | Horizon(s) Description | Zone | Temporal Analysis | Baseline Well Network | Optimal Well Network | Well Reduction | Baseline Samples | Optimal Samples | Sample Reduction |
|---|---|---|---|---|---|---|---|---|---|---|
| Hunter | 3 | 3 Horizons; SGZ, UZUU, UZLU-LZ | 2.5D | Iterative Thinning | 208 | 151 | 27% | 707 | 151 | 79% |
| Atkinson | 3 | Default Horizons | 2.5D | Iterative Thinning | 208 | 167 | 20% | 707 | 167 | 76% |
| Atkinson | 1 | All horizons merged | 2D | Iterative Thinning | 208 | 187 | 10% | 707 | 187 | 74% |

**GTS Analysis of AFP44, AFCEE Analysis, Analyst #2**

**SOFTWARE TESTING OF GTS FOR AFCEE ENVIRONMENTAL SECURITY TECHNOLOGY CERTIFICATION PROGRAM (ESTCP) PROJECT ER-07-14 DECEMBER 2009 AND APRIL 2010**

**Introduction**

Jon Atkinson, AFCEE/TDV, tested the 29 Oct, 11Nov, and 15 Mar 2010 beta versions of Geostatistical Temporal/Spatial (GTS) Software for Optimization of Long-Term Monitoring Networks using electronic ASCII data files for the large groundwater contaminant plumes associated with AF Plant 44 (AFP 44) located near Tucson, Arizona. Software testing was conducted on both Windows XP and Vista operating systems. This report is divided into two major topics: (1) Usability of the software; and (2) Discussion of the case study.

**Usability of GTS Software**

This tester rates the general usability of GTS as very good considering it is in beta form. Its modular structure is logical and relatively easy for the minimally experienced geostatistical practitioner to use. Installation and security and administrative rights elements of set up were performed by AFCEE/OSS personnel so the tester cannot adequately evaluate this component of the software.

The large ASCII data file provided by Dr. Kirk Cameron was in ERPIMS format and required very little modification to successfully run in GTS. The RL field was populated with “0.5 ug/L” and numerous missing MDL values were populated with the value “0.5 ug/L.”

The five major modules coupled with Windows menu and dialog boxes allow an environmental professional with limited statistical training and expertise to navigate successfully through the many spatial and temporal elements of GTS. The graphical user interface (GUI) appears to be highly functional and user friendly. The ability on output graphs to change from linear to logarithmic units and to pan comprises a notable graphical robustness.

The software tester encountered numerous bugs and runtime errors while running the GTS 29 Oct and 11 Nov builds, some of which were fatal, causing shutdown of GTS. These problems occurred both in the XP environment as well as in Vista. These runtime errors are described in detail in the next section. The 15 Mar '10 version was run on Windows XP utilizing the input file used for the 2009 testing. No runtime errors or "bugs" were encountered.

The user's guide provides a good introduction to the GTS algorithm and helpful instructions in preparing input data files and navigating through the five modules and numerous submodules. My suggestions for enhancing the quality of the User's Guide encompass the following:

1. Expand the Acronyms section by adding BW, ASCII, PQL and other acronyms contained in the guide.
2. Page 14, Sec 3.3.1, Para 1, Sent 1: Briefly and succinctly describe the Tukey's univariate box plot, possibly in a glossary.
3. Page 18, Sec 4.1.2: Suggest labeling the appropriate statistical parameters (e.g., median, U/L quartiles) on the box plot.
4. Page 28, Section 4.3.5, Para 2: The guide asserts that GTS needs at least 20 wells or data points to perform valid statistical analysis. For many small and moderate size groundwater contaminant plumes, many horizons or even all horizons may contain less than 20 wells with multiple sampling events. This seems to be a real limitation of GTS. Recommend the guide address this issue and that it recommend other statistical codes (e.g., MAROS) that may be appropriate for this limited amount of data points with multiple data sets.
5. Page 34, Sec 5.2.2, Para 1: Suggest defining Theil-Sen trends in a glossary.
6. Page 36, Sec 5.2.3, Note 1: Suggest defining Sen's slope in a glossary.
7. Page 50, Sec 6.2.1, Para 1: Recommend adding "bit strings" to a glossary.

The GTS saving and reporting capabilities are excellent. As a MAROS user and tester, this robust saving capability is highly appreciated. One enhancement that would improve reporting capability would be the ability to save reports in Word and ASCII formats.

Regarding suggested improvements to GTS, a minor enhancement to the graphical capability would be the ability to modify the x and y axes on many of the graphs, in addition to changing from log to linear y axis and vice versa. Some graphs have incomplete legends. An example is the graph "timeseries_baseline_and_ confidence_G16." In the Explore module, "Post-plots by COC," the upper x-axis is titled "NPL: Maximum Deciles for . . ." The meaning or significance of "NPL" is not apparent to this tester. Should "NPL" occur here? A potential improvement would be to modify the error messages so that noncomputer-programmer users could understand the nature of most of the errors.

For the April 2010 runs, the Baseline temporal variogram (G24) depicts the confidence band; however, the legend does not state if this is a 90-percent confidence interval or another interval (see Temporal Variogram 0414.ppt). Suggest the percentage of the confidence interval be annotated in the legends for these variograms.

**Case Study Discussion**

The 29 Oct build was used on a laptop (Compaq 8510p) computer equipped with Windows Vista and a docking station to evaluate the AFP 44 dataset provided by Dr. Kirk Cameron. Minor changes to the dataset were made during the input process. All GTS defaults were accepted, no water-level data or GIS shape files were input, no combining of aquifer zones was performed, and 2.5D groundwater horizon analysis type was selected.

As testing proceeded, output tables were saved as html files (see attached). No problems or error messages were encountered until the View button for “Baseline: Plume Extent, Basemap Extent and Magnitude of . . .” (see attached Error Messages 1105.pptx) was activated. A runtime error resulted in abnormal program termination. This tester proceeded to Optimize: Spatial redundancy, where clicking on Calculate for Cost-Accuracy Tradeoff Curves caused an error message to appear on the screen and then termination of computation. Proceeding on the same Optimize screen to “Optimal Map, Concentration Estimates” resulted in an error message. Going to the next screen, Network adequacy, error messages were produced for both Generate and Uncertainty CVs. At this point, testing of the 29 Oct version terminated because of numerous uncalculated statistical parameters.

The 11 Nov build was installed on a laptop (Dell Latitude D620) running on Windows XP. The same input file, default settings and 2.5D analysis type were selected as above. GTS appeared to be performing well; however, the table generated for Optimize: Temporal redundancy, Temporal Variogram Report had all NA values for column heading “Optimal Sampling Interval (days).” Reports generated by GTS are attached as html files. Continuing to the next GTS screen, clicking on “Calculate” for “Cost-Accuracy Tradeoff Curves” caused an error message to appear on the screen (see file AFP 44 Run 2 Errors.pptx) and caused termination of computation. Proceeding to Optimal Map, Concentration Estimates caused GTS to lockup and shut down as revealed by the Task Manager “not responding” status. At this point the tester terminated GTS beta testing.

The 15 Mar build was tested on a laptop (Dell Latitude D620) running on Windows XP during the timeframe 14 – 28 Apr 2010. Simulations were run for both groundwater horizon types 2D and 2.5D (AFP44 Run 0414.gts and AFP44 Run 0427.gts, respectively). No merging of the four aquifer zones was performed. All components of the first four modules performed adequately.

The Iterative Thinning Report documents (html file attached) an average base median sampling interval of approximately quarterly for AFP 44 and an optimal median sampling interval of about annually. This represents a significant sampling frequency reduction and a resulting significant potential cost savings.

## AFP44 OPTIMIZATION RESULTS — DATABASE VERSION 1

# GTS Optimized Network Status Report

### Summary of Optimized Status for Each Well as Identified by GTS using the NPL Dataset

Project = afp44_v1_100209
AFIID/Site = NA
Date Completed = August 5, 2010
Author = MacStat Consulting/Kirk Cameron

### Using Iterative Thinning

| GTS Well ID | Loc ID | Well Type | Easting | Northing | Sample Elevation | Vertical Zone | Protected Status | Critical Status | Critical Index | Baseline Frequency (per year) | Baseline Interval (days) | Well-Specific Optimal Frequency (per year) | Well-Specific Optimal Interval (days) | Zone-Based Optimal Frequency (per year) | Zone-Based Optimal Interval (days) | Site-Based Optimal Frequency (per year) | Site-Based Optimal Interval (days) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | B-01 | MNW | 798056.54 | 401594.26 | 2491.19 | SGZ | No | No | 0.4 | 22Q (0.1818) | 1967 | 2Q (2) | 194 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 2 | B-02 | MNW | 798257.19 | 401530.72 | 2495.675 | SGZ | No | No | 0.4 | 22Q (0.1818) | 1967 | 2Q (2) | 222 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 3 | B-03 | MNW | 798376.18 | 401421.12 | 2489.515 | SGZ | No | No | 0.4 | 22Q (0.1818) | 1966.5 | 3Q (1.33) | 282 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 4 | B-09 | MNW | 799076.39 | 401722.9 | 2495.02 | SGZ | No | No | 0.4 | 22Q (0.1818) | 1944 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 5 | CRED_UN | MNW | 797533.99 | 403467.37 | 2417.61 | UZUU | No | Yes | 0.6111 | 1Q (4) | 99.5 | 4Q (1) | 354 | 4Q (1) | 361 | 4Q (1) | 364 |
| 6 | E-01 | EXW | 799007.39 | 403182.99 | 2424.87 | UZUU | No | Yes | 0.6667 | 1Q (4) | 105 | 5Q (0.8) | 480 | 4Q (1) | 361 | 4Q (1) | 364 |
| 7 | E-02 | EXW | 798073.88 | 403184.48 | 2435.48 | UZUU | No | Yes | 0.5 | 1Q (4) | 90 | 5Q (0.8) | 480 | 4Q (1) | 361 | 4Q (1) | 364 |
| 8 | E-03 | EXW | 797547.8 | 403926.13 | 2456.88 | UZUU | No | Yes | 0.7273 | 1Q (4) | 89.5 | 5Q (0.8) | 480 | 4Q (1) | 361 | 4Q (1) | 364 |
| 9 | E-04 | EXW | 796273.11 | 404182.38 | 2443.98 | LZ-UZLU | No | Yes | 0.6364 | 1Q (4) | 89 | 4Q (1) | 364 | 4Q (1) | 364 | 4Q (1) | 364 |
| 10 | E-04M | OBS | 796268.22 | 404169.48 | 2403.74 | LZ-UZLU | No | No | 0 | NA (NA) | NA | NA | NA | 4Q (1) | 364 | 4Q (1) | 364 |
| 11 | E-05 | EXW | 797073.56 | 405795.6 | 2465.53 | UZUU | No | Yes | 0.875 | 2Q (2) | 141 | 1Q (4) | 103 | 4Q (1) | 361 | 4Q (1) | 364 |
| 12 | E-06 | IJW | 795211.8 | 405885.1 | 2427.955 | LZ-UZLU | No | Yes | 1 | 1Q (4) | 91 | 3Q (1.33) | 291 | 4Q (1) | 364 | 4Q (1) | 364 |
| 13 | E-09 | IJW | 794058 | 408028 | 2435.03 | LZ-UZLU | No | No | 0.2222 | 1Q (4) | 91 | 2Q (2) | 190 | 4Q (1) | 364 | 4Q (1) | 364 |
| 14 | E-09R | EXW | 794742.12 | 407666.34 | 2418.1 | LZ-UZLU | No | No | 0.3333 | NA (NA) | NA | NA | NA | 4Q (1) | 364 | 4Q (1) | 364 |
| 15 | E-10 | EXW | 805750.82 | 399878.85 | 2489.12 | UZUU | No | Yes | 0.6471 | 1Q (4) | 89 | 4Q (1) | 358 | 4Q (1) | 361 | 4Q (1) | 364 |
| 16 | E-12 | EXW | 803038.67 | 402196.53 | 2483.09 | UZUU | No | Yes | 0.6818 | 1Q (4) | 93 | 4Q (1) | 331 | 4Q (1) | 361 | 4Q (1) | 364 |
| 17 | E-13 | EXW | 801723.99 | 403018.54 | 2400.64 | UZUU | No | Yes | 0.5455 | 1Q (4) | 91 | 3Q (1.33) | 291 | 4Q (1) | 361 | 4Q (1) | 364 |
| 18 | E-14 | EXW | 801158.66 | 402109.87 | 2435.07 | UZUU | No | No | 0.35 | 1Q (4) | 92 | 5Q (0.8) | 491 | 4Q (1) | 361 | 4Q (1) | 364 |
| 19 | E-15 | EXW | 800300.77 | 402100.36 | 2461.04 | UZUU | No | Yes | 0.5 | 1Q (4) | 91 | 5Q (0.8) | 416 | 4Q (1) | 361 | 4Q (1) | 364 |
| 20 | E-16 | EXW | 806475.42 | 399369.86 | 2521.51 | UZUU | No | Yes | 0.6875 | 1Q (4) | 91 | 4Q (1) | 390 | 4Q (1) | 361 | 4Q (1) | 364 |
| 21 | E-17 | EXW | 797288.33 | 402072.31 | 2451.45 | UZUU | No | Yes | 0.7273 | 1Q (4) | 89 | 5Q (0.8) | 407 | 4Q (1) | 361 | 4Q (1) | 364 |
| 22 | E-18 | EXW | 800167.13 | 402623.36 | 2451.225 | UZUU | No | Yes | 0.7273 | 1Q (4) | 91 | 5Q (0.8) | 416 | 4Q (1) | 361 | 4Q (1) | 364 |
| 23 | E-19 | EXW | 801169.92 | 401892.96 | 2542.655 | UZUU | No | Yes | 0.5 | 1Q (4) | 91 | 5Q (0.8) | 416 | 4Q (1) | 361 | 4Q (1) | 364 |
| 24 | E-20 | EXW | 806333.62 | 399981.5 | 2477.6 | UZUU | No | No | 0.4286 | 1Q (4) | 91 | 5Q (0.8) | 416 | 4Q (1) | 361 | 4Q (1) | 364 |
| 25 | E-21 | EXW | 801287.98 | 401954.74 | 2466.7 | UZUU | No | Yes | 0.6111 | 1Q (4) | 92 | 5Q (0.8) | 421 | 4Q (1) | 361 | 4Q (1) | 364 |
| 26 | E-22 | EXW | 806319.52 | 399642.19 | 2490.17 | UZUU | No | Yes | 0.5333 | 1Q (4) | 102 | 1Q (4) | 118 | 4Q (1) | 361 | 4Q (1) | 364 |
| 27 | E-23 | EXW | 798497.96 | 402380.08 | 2384.075 | UZUU | No | Yes | 0.5455 | 1Q (4) | 92 | 5Q (0.8) | 491 | 4Q (1) | 361 | 4Q (1) | 364 |
| 28 | E-24 | EXW | 796879.64 | 403145.68 | 2388.575 | UZUU | No | Yes | 0.6818 | 1Q (4) | 90 | 4Q (1) | 360 | 4Q (1) | 361 | 4Q (1) | 364 |
| 29 | EL-01 | EXW | 803442.01 | 400602.03 | 2342.33 | LZ-UZLU | No | Yes | 0.6429 | 1Q (4) | 96 | 6Q (0.67) | 504 | 4Q (1) | 364 | 4Q (1) | 364 |
| 30 | EL-02 | EXW | 801093.21 | 403218.95 | 2351.8 | LZ-UZLU | No | Yes | 0.5455 | 1Q (4) | 91 | 5Q (0.8) | 485 | 4Q (1) | 364 | 4Q (1) | 364 |
| 31 | EL-03 | EXW | 799307.61 | 403114.85 | 2275.94 | LZ-UZLU | No | Yes | 0.5909 | 1Q (4) | 91 | 4Q (1) | 364 | 4Q (1) | 364 | 4Q (1) | 364 |
| 32 | EL-04 | EXW | 796985.35 | 403395.42 | 2222.82 | LZ-UZLU | No | No | 0.4737 | 1Q (4) | 89 | 6Q (0.67) | 570 | 4Q (1) | 364 | 4Q (1) | 364 |
| 33 | EPA-01 | MNW | 795412.13 | 403906.29 | 2430.86 | LZ-UZLU | No | Yes | 0.6818 | 1Q (4) | 91 | 5Q (0.8) | 416 | 4Q (1) | 364 | 4Q (1) | 364 |
| 34 | EPA-02 | MNW | 796632.8 | 404558.26 | 2437.54 | UZUU | No | Yes | 0.8889 | 1Q (4) | 102 | 5Q (0.8) | 435 | 4Q (1) | 361 | 4Q (1) | 364 |
| 35 | EPA-02A | MNW | 796647.63 | 404489.82 | 2222.25 | LZ-UZLU | No | Yes | 0.7222 | 1Q (4) | 98 | 3Q (1.33) | 314 | 4Q (1) | 364 | 4Q (1) | 364 |
| 36 | EPA-03 | MNW | 798228.45 | 405950.46 | 2385.04 | LZ-UZLU | Yes | Yes | 1 | 1Q (4) | 99 | 3Q (1.33) | 282 | 4Q (1) | 364 | 4Q (1) | 364 |
| 37 | EPA-04 | MNW | 794893.49 | 405309.34 | 2431.72 | LZ-UZLU | No | No | 0.4286 | 1Q (4) | 103 | 3Q (1.33) | 264 | 4Q (1) | 364 | 4Q (1) | 364 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 38 | EPA-05 | MNW | 795813.2 | 406960.83 | 2434.44 | LZ-UZLU | No | Yes | 0.6154 | 1Q (4) | 104 | 5Q (0.8) | 475 | 4Q (1) | 364 | 4Q (1) | 364 |
| 39 | M-01A | MNW | 804027.27 | 403174.06 | 2442.25 | LZ-UZLU | No | Yes | 0.6 | 4Q (1) | 361 | NA | NA | 4Q (1) | 364 | 4Q (1) | 364 |
| 40 | M-01B | MNW | 804048.21 | 403173.35 | 2292.67 | LZ-UZLU | No | Yes | 0.8 | 3Q (1.3333) | 266 | NA | NA | 4Q (1) | 364 | 4Q (1) | 364 |
| 41 | M-02A | EXW | 798123.41 | 402318.17 | 2498.74 | SGZ | No | No | 0.3333 | NA (NA) | NA | 5Q (0.8) | 448 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 42 | M-02B | MNW | 798108.33 | 402328.7 | 2449.37 | UZUU | No | Yes | 0.8333 | 1Q (4) | 106 | 4Q (1) | 377 | 4Q (1) | 361 | 4Q (1) | 364 |
| 43 | M-02C | MNW | 798103.46 | 402350.52 | 2124.41 | LZ-UZLU | No | Yes | 0.9333 | 1Q (4) | 105 | 3Q (1.33) | 268 | 4Q (1) | 364 | 4Q (1) | 364 |
| 44 | M-03A | MNW | 801465.81 | 402946.47 | 2459.71 | UZUU | No | Yes | 0.6111 | 1Q (4) | 103 | 5Q (0.8) | 412 | 4Q (1) | 361 | 4Q (1) | 364 |
| 45 | M-03B | MNW | 801466.3 | 402974.67 | 2325.38 | LZ-UZLU | No | Yes | 0.8333 | 1Q (4) | 95.5 | 3Q (1.33) | 278 | 4Q (1) | 364 | 4Q (1) | 364 |
| 46 | M-05 | MNW | 801029.48 | 402082.38 | 2470.97 | UZUU | No | Yes | 0.5 | 1Q (4) | 91 | 3Q (1.33) | 291 | 4Q (1) | 361 | 4Q (1) | 364 |
| 47 | M-06 | MNW | 799826.19 | 403798.37 | 2464.92 | UZUU | No | Yes | 0.7368 | 1Q (4) | 105 | 4Q (1) | 389 | 4Q (1) | 361 | 4Q (1) | 364 |
| 48 | M-07 | MNW | 798667.11 | 403188.45 | 2460.01 | UZUU | No | No | 0.3684 | 1Q (4) | 104 | 6Q (0.67) | 555 | 4Q (1) | 361 | 4Q (1) | 364 |
| 49 | M-08 | MNW | 797792.02 | 402711.76 | 2451.83 | UZUU | No | No | 0.2778 | 1Q (4) | 92 | 4Q (1) | 327 | 4Q (1) | 361 | 4Q (1) | 364 |
| 50 | M-09 | MNW | 799305.28 | 401745.31 | 2454.91 | UZUU | No | Yes | 0.6111 | 1Q (4) | 92.5 | 4Q (1) | 370 | 4Q (1) | 361 | 4Q (1) | 364 |
| 51 | M-10 | MNW | 798188.37 | 401559.72 | 2445.59 | UZUU | No | Yes | 0.6667 | 1Q (4) | 92 | 3Q (1.33) | 268 | 4Q (1) | 361 | 4Q (1) | 364 |
| 52 | M-100 | MNW | 801104.3 | 402435.3 | 2463.47 | UZUU | No | No | 0.2 | 1Q (4) | 94.5 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 53 | M-101 | MNW | 800870.4 | 402568.8 | 2463.19 | UZUU | No | Yes | 0.5833 | 1Q (4) | 97.5 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 54 | M-102 | MNW | 801472 | 402472 | 2464.345 | UZUU | No | No | 0.4667 | 1Q (4) | 94 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 55 | M-103 | MNW | 802787 | 402313.9 | 2473.985 | UZUU | No | Yes | 0.6667 | 1Q (4) | 92.5 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 56 | M-104 | MNW | 801202.3 | 402612.3 | 2465.66 | UZUU | No | No | 0.2667 | 1Q (4) | 134 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 57 | M-105 | MNW | 800883.5 | 402775.7 | 2461.825 | UZUU | No | Yes | 0.6875 | 2Q (2) | 141 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 58 | M-106M | MNW | 802822.32 | 402286.36 | 2477.54 | UZUU | No | No | 0 | NA (NA) | NA | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 59 | M-11 | MNW | 800933.91 | 403231.42 | 2457.82 | UZUU | No | Yes | 0.7778 | 1Q (4) | 117 | 5Q (0.8) | 416 | 4Q (1) | 361 | 4Q (1) | 364 |
| 60 | M-12A | MNW | 796892.76 | 403187.78 | 2433.07 | UZUU | No | Yes | 0.6111 | 1Q (4) | 103 | 4Q (1) | 330 | 4Q (1) | 361 | 4Q (1) | 364 |
| 61 | M-12B | MNW | 796951.98 | 403189.67 | 2294.52 | LZ-UZLU | No | Yes | 0.6667 | 1Q (4) | 96 | 3Q (1.33) | 307 | 4Q (1) | 364 | 4Q (1) | 364 |
| 62 | M-13 | MNW | 796877.98 | 402300.19 | 2447.17 | UZUU | No | Yes | 0.7222 | 1Q (4) | 124 | 4Q (1) | 361 | 4Q (1) | 361 | 4Q (1) | 364 |
| 63 | M-14 | MNW | 796822.16 | 401070.61 | 2442.28 | UZUU | No | Yes | 0.8125 | 1Q (4) | 99 | 5Q (0.8) | 451 | 4Q (1) | 361 | 4Q (1) | 364 |
| 64 | M-15 | MNW | 801484.8 | 399684.67 | 2522.91 | UZUU | No | Yes | 0.7222 | 1Q (4) | 131.5 | 4Q (1) | 324 | 4Q (1) | 361 | 4Q (1) | 364 |
| 65 | M-16 | MNW | 803566.54 | 400632.94 | 2456.19 | UZUU | No | No | 0.4706 | 1Q (4) | 99.5 | 2Q (2) | 217 | 4Q (1) | 361 | 4Q (1) | 364 |
| 66 | M-17 | MNW | 805014.84 | 400443.98 | 2503.16 | UZUU | No | Yes | 0.7778 | 1Q (4) | 91 | 3Q (1.33) | 291 | 4Q (1) | 361 | 4Q (1) | 364 |
| 67 | M-18 | MNW | 806296.77 | 399751.23 | 2498.26 | UZUU | No | No | 0.3684 | 1Q (4) | 81 | 4Q (1) | 316 | 4Q (1) | 361 | 4Q (1) | 364 |
| 68 | M-19 | MNW | 803861.53 | 398687.9 | 2466.81 | UZUU | No | Yes | 0.7059 | 1Q (4) | 93 | 5Q (0.8) | 439 | 4Q (1) | 361 | 4Q (1) | 364 |
| 69 | M-20 | MNW | 802918.35 | 402393.23 | 2480.08 | UZUU | No | Yes | 0.7222 | 1Q (4) | 92 | 4Q (1) | 327 | 4Q (1) | 361 | 4Q (1) | 364 |
| 70 | M-21 | MNW | 808528.71 | 398208.72 | 2471.13 | LZ-UZLU | No | Yes | 0.6154 | 4Q (1) | 358.5 | NA | NA | 4Q (1) | 364 | 4Q (1) | 364 |
| 71 | M-22A | MNW | 796928.21 | 399116.38 | 2444.02 | UZUU | No | Yes | 0.5 | 4Q (1) | 317.5 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 72 | M-22B | MNW | 796943.91 | 399069.51 | 2251.64 | LZ-UZLU | No | Yes | 0.75 | 4Q (1) | 317 | NA | NA | 4Q (1) | 364 | 4Q (1) | 364 |
| 73 | M-23 | MNW | 800053.31 | 403231.67 | 2434.53 | UZUU | No | No | 0.3333 | 1Q (4) | 106 | 4Q (1) | 377 | 4Q (1) | 361 | 4Q (1) | 364 |
| 74 | M-24A | MNW | 799369.12 | 400532.94 | 2441.235 | UZUU | No | Yes | 0.8235 | 1Q (4) | 120 | 3Q (1.33) | 295 | 4Q (1) | 361 | 4Q (1) | 364 |
| 75 | M-24B | MNW | 799423.64 | 400552.58 | 2328.565 | LZ-UZLU | No | Yes | 0.8 | 1Q (4) | 91.5 | 4Q (1) | 370 | 4Q (1) | 364 | 4Q (1) | 364 |
| 76 | M-25 | MNW | 801509.92 | 401122.49 | 2451.78 | UZUU | No | Yes | 0.7778 | 1Q (4) | 104 | 5Q (0.8) | 444 | 4Q (1) | 361 | 4Q (1) | 364 |
| 77 | M-26 | MNW | 803511.15 | 400612.14 | 2255.15 | LZ-UZLU | No | Yes | 0.7692 | 1Q (4) | 94.5 | 3Q (1.33) | 300 | 4Q (1) | 364 | 4Q (1) | 364 |
| 78 | M-27 | MNW | 805921.77 | 399978.43 | 2319.36 | LZ-UZLU | No | Yes | 0.6923 | 1Q (4) | 98.5 | 11Q (0.36) | 952 | 4Q (1) | 364 | 4Q (1) | 364 |
| 79 | M-28 | MNW | 804974.79 | 401904.79 | 2477.84 | UZUU | No | Yes | 0.875 | 2Q (2) | 178 | 6Q (0.67) | 518 | 4Q (1) | 361 | 4Q (1) | 364 |
| 80 | M-29 | MNW | 799663.69 | 403685.67 | 2306.6 | LZ-UZLU | No | Yes | 0.8889 | 1Q (4) | 95.5 | 2Q (2) | 180 | 4Q (1) | 364 | 4Q (1) | 364 |
| 81 | M-30 | MNW | 802282.99 | 403454.55 | 2452.3 | UZUU | No | Yes | 0.8947 | 1Q (4) | 127 | 14Q (0.29) | 1270 | 4Q (1) | 361 | 4Q (1) | 364 |
| 82 | M-31 | MNW | 800224.97 | 405337.2 | 2442.61 | UZUU | No | Yes | 0.6923 | 4Q (1) | 362.5 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 83 | M-32 | MNW | 798522.44 | 404841.11 | 2452.61 | UZUU | No | Yes | 0.6429 | 1Q (4) | 95 | 4Q (1) | 348 | 4Q (1) | 361 | 4Q (1) | 364 |
| 84 | M-33 | MNW | 803164.27 | 404469.49 | 2446.91 | UZUU | No | Yes | 0.5714 | 4Q (1) | 362 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 85 | M-34 | MNW | 796597.51 | 405953.88 | 2421.43 | UZUU | No | No | 0.3333 | 1Q (4) | 87 | 2Q (2) | 166 | 4Q (1) | 361 | 4Q (1) | 364 |
| 86 | M-35 | MNW | 798091.64 | 407948.44 | 2385.24 | LZ-UZLU | No | Yes | 0.5333 | 1Q (4) | 102 | 4Q (1) | 333 | 4Q (1) | 364 | 4Q (1) | 364 |
| 87 | M-36 | MNW | 795350.73 | 408364.35 | 2419.47 | UZUU | No | Yes | 0.7857 | 1Q (4) | 98 | 2Q (2) | 224 | 4Q (1) | 361 | 4Q (1) | 364 |
| 88 | M-37 | MNW | 793518.41 | 406853.41 | 2420.79 | LZ-UZLU | No | Yes | 0.875 | 4Q (1) | 364 | 11Q (0.36) | 971 | 4Q (1) | 364 | 4Q (1) | 364 |
| 89 | M-38 | MNW | 793192.56 | 404197.61 | 2433.37 | UZUU | No | Yes | 0.8667 | 4Q (1) | 367 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 90 | M-39 | MNW | 795046.48 | 401577.17 | 2440.03 | LZ-UZLU | No | Yes | 0.9333 | 4Q (1) | 364 | 32Q (0.12) | 2912 | 4Q (1) | 364 | 4Q (1) | 364 |
| 91 | M-40 | MNW | 795219.91 | 405888.09 | 2417.89 | UZUU | No | Yes | 0.875 | 1Q (4) | 94 | 3Q (1.33) | 279 | 4Q (1) | 361 | 4Q (1) | 364 |
| 92 | M-41 | MNW | 800165.75 | 402424.05 | 2459.84 | UZUU | No | Yes | 0.6667 | 1Q (4) | 96 | 4Q (1) | 341 | 4Q (1) | 361 | 4Q (1) | 364 |
| 93 | M-42 | MNW | 801761.55 | 400521.14 | 2470.19 | UZUU | No | Yes | 0.5 | NA (NA) | NA | 3Q (1.33) | 295 | 4Q (1) | 361 | 4Q (1) | 364 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 94 | M-43 | MNW | 799925.69 | 400144.58 | 2469.69 | UZUU | No | Yes | 0.5 | NA (NA) | NA | 4Q (1) | 356 | 4Q (1) | 361 | 4Q (1) | 364 |
| 95 | M-44 | MNW | 800920.83 | 400916.07 | 2461.49 | UZUU | No | Yes | 0.5 | NA (NA) | NA | 4Q (1) | 329 | 4Q (1) | 361 | 4Q (1) | 364 |
| 96 | M-45 | MNW | 800059.53 | 401776.85 | 2456.54 | UZUU | No | Yes | 1 | 8Q (0.5) | 746 | 15Q (0.27) | 1330 | 4Q (1) | 361 | 4Q (1) | 364 |
| 97 | M-46 | MNW | 799773.86 | 401768.31 | 2447.3 | UZUU | No | Yes | 0.65 | 2Q (2) | 174 | 4Q (1) | 398 | 4Q (1) | 361 | 4Q (1) | 364 |
| 98 | M-47 | MNW | 799502.89 | 401760.67 | 2451.72 | UZUU | No | Yes | 0.5333 | 2Q (2) | 175 | 4Q (1) | 350 | 4Q (1) | 361 | 4Q (1) | 364 |
| 99 | M-48 | MNW | 799184.13 | 401750.74 | 2460.96 | UZUU | No | Yes | 0.5294 | 2Q (2) | 177 | 9Q (0.44) | 800 | 4Q (1) | 361 | 4Q (1) | 364 |
| 100 | M-49 | MNW | 798879.76 | 401741.91 | 2458.58 | UZUU | No | Yes | 0.5 | 1Q (4) | 100 | 1Q (4) | 131 | 4Q (1) | 361 | 4Q (1) | 364 |
| 101 | M-50 | MNW | 798631.49 | 401733.56 | 2459.2 | UZUU | No | No | 0.4211 | 2Q (2) | 182 | 4Q (1) | 388 | 4Q (1) | 361 | 4Q (1) | 364 |
| 102 | M-51 | MNW | 798639.73 | 401443.8 | 2460.03 | UZUU | No | No | 0.3846 | 2Q (2) | 181 | 5Q (0.8) | 446 | 4Q (1) | 361 | 4Q (1) | 364 |
| 103 | M-52 | MNW | 800277.05 | 401993.78 | 2446.53 | UZUU | No | Yes | 1 | 5Q (0.8) | 430.5 | 8Q (0.5) | 689 | 4Q (1) | 361 | 4Q (1) | 364 |
| 104 | M-53 | MNW | 800696.91 | 402059.48 | 2447.7 | UZUU | No | No | 0.3333 | 2Q (2) | 169 | 4Q (1) | 386 | 4Q (1) | 361 | 4Q (1) | 364 |
| 105 | M-54 | MNW | 801220.42 | 401477.74 | 2452.7 | UZUU | No | Yes | 0.5 | NA (NA) | NA | 4Q (1) | 348 | 4Q (1) | 361 | 4Q (1) | 364 |
| 106 | M-55A | MNW | 800850.73 | 398052.71 | 2444.74 | UZUU | No | Yes | 0.8 | 1Q (4) | 95 | 3Q (1.33) | 276 | 4Q (1) | 361 | 4Q (1) | 364 |
| 107 | M-56 | MNW | 798642.66 | 398017.7 | 2450.425 | UZUU | No | Yes | 0.8 | 1Q (4) | 91 | 2Q (2) | 225 | 4Q (1) | 361 | 4Q (1) | 364 |
| 108 | M-57 | MNW | 799437.86 | 400468.8 | 2500.935 | SGZ | No | Yes | 0.8 | 2Q (2) | 191 | 3Q (1.33) | 283 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 109 | M-58 | MNW | 804077.54 | 398087.25 | 2455.84 | UZUU | No | Yes | 1 | 1Q (4) | 90 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 110 | M-59 | MNW | 803675 | 398209.64 | 2446.625 | LZ-UZLU | No | No | 0.4 | 1Q (4) | 90 | NA | NA | 4Q (1) | 364 | 4Q (1) | 364 |
| 111 | M-60 | MNW | 803853.79 | 402953.58 | 2457.005 | UZUU | No | Yes | 0.7692 | 1Q (4) | 95 | 6Q (0.67) | 496 | 4Q (1) | 361 | 4Q (1) | 364 |
| 112 | M-61 | MNW | 804183.14 | 398022.36 | 2443.67 | LZ-UZLU | No | Yes | 0.9231 | 1Q (4) | 100 | 4Q (1) | 358 | 4Q (1) | 364 | 4Q (1) | 364 |
| 113 | M-62 | MNW | 804182.26 | 398039.18 | 2474.21 | UZUU | No | No | 0.2 | 1Q (4) | 90 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 114 | M-63 | MNW | 804196.88 | 398032.44 | 2492.185 | UZUU | No | Yes | 0.6154 | 1Q (4) | 98.5 | 3Q (1.33) | 235 | 4Q (1) | 361 | 4Q (1) | 364 |
| 115 | M-64 | MNW | 806348.31 | 399856.59 | 2466.105 | UZUU | No | Yes | 0.6429 | 1Q (4) | 97 | 2Q (2) | 222 | 4Q (1) | 361 | 4Q (1) | 364 |
| 116 | M-65 | MNW | 806352.62 | 399885.98 | 2483.33 | UZUU | No | Yes | 0.5 | 1Q (4) | 97 | 3Q (1.33) | 230 | 4Q (1) | 361 | 4Q (1) | 364 |
| 117 | M-66 | MNW | 806349.84 | 399871.75 | 2499.415 | UZUU | No | Yes | 0.8333 | 6Q (0.6667) | 535.5 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 118 | M-67 | MNW | 801183.91 | 401972.44 | 2399.57 | LZ-UZLU | No | Yes | 0.7333 | 1Q (4) | 96 | 4Q (1) | 325 | 4Q (1) | 364 | 4Q (1) | 364 |
| 119 | M-68 | MNW | 801209.71 | 401947.07 | 2442.505 | UZUU | No | Yes | 0.6111 | 1Q (4) | 96.5 | 3Q (1.33) | 281 | 4Q (1) | 361 | 4Q (1) | 364 |
| 120 | M-69 | MNW | 801186.42 | 401922.29 | 2469.515 | UZUU | No | Yes | 0.5 | 1Q (4) | 94 | 3Q (1.33) | 231 | 4Q (1) | 361 | 4Q (1) | 364 |
| 121 | M-70 | MNW | 804949.23 | 399606.17 | 2473.685 | UZUU | No | Yes | 0.7692 | 1Q (4) | 109 | 4Q (1) | 326 | 4Q (1) | 361 | 4Q (1) | 364 |
| 122 | M-71 | MNW | 804523.06 | 397722.13 | 2496.39 | UZUU | No | Yes | 0.8 | 1Q (4) | 90 | 2Q (2) | 169 | 4Q (1) | 361 | 4Q (1) | 364 |
| 123 | M-74 | MNW | 804056.26 | 397734.78 | 2494.79 | UZUU | No | Yes | 0.6154 | 1Q (4) | 95 | 2Q (2) | 217 | 4Q (1) | 361 | 4Q (1) | 364 |
| 124 | M-75 | MNW | 803915.37 | 398152.76 | 2494.615 | UZUU | No | Yes | 0.6923 | 1Q (4) | 98.5 | 12Q (0.33) | 1051 | 4Q (1) | 361 | 4Q (1) | 364 |
| 125 | M-76C | MNW | 803107.09 | 402202.69 | 2467.67 | UZUU | No | Yes | 0.6667 | NA (NA) | NA | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 126 | M-77 | MNW | 801886.47 | 402079.72 | 2400.08 | UZUU | No | No | 0.3889 | 2Q (2) | 164.5 | 4Q (1) | 351 | 4Q (1) | 361 | 4Q (1) | 364 |
| 127 | M-78 | MNW | 798659.21 | 399085.78 | 2449.53 | UZUU | No | Yes | 0.9231 | 2Q (2) | 174 | 5Q (0.8) | 428 | 4Q (1) | 361 | 4Q (1) | 364 |
| 128 | M-79 | MNW | 797026.19 | 398026.27 | 2443.34 | LZ-UZLU | No | No | 0.3077 | 1Q (4) | 131.5 | NA | NA | 4Q (1) | 364 | 4Q (1) | 364 |
| 129 | M-80 | MNW | 801867.59 | 402622.66 | 2450.905 | UZUU | No | Yes | 0.6111 | 2Q (2) | 169.5 | 5Q (0.8) | 417 | 4Q (1) | 361 | 4Q (1) | 364 |
| 130 | M-82 | MNW | 806621.82 | 399247.35 | 2481.59 | UZUU | No | Yes | 0.6667 | 1Q (4) | 114 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 131 | M-83 | MNW | 806245.19 | 399512.77 | 2479.555 | UZUU | No | Yes | 0.6667 | 1Q (4) | 118 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 132 | M-84 | MNW | 806486.74 | 399592.67 | 2483.48 | UZUU | No | Yes | 0.5833 | 1Q (4) | 99.5 | 2Q (2) | 163 | 4Q (1) | 361 | 4Q (1) | 364 |
| 133 | M-85 | MNW | 806553.66 | 399838.42 | 2481.33 | UZUU | No | Yes | 0.5833 | 2Q (2) | 180 | 3Q (1.33) | 307 | 4Q (1) | 361 | 4Q (1) | 364 |
| 134 | M-86 | MNW | 806005.19 | 399614.58 | 2478.25 | UZUU | No | No | 0.4167 | 1Q (4) | 105 | 2Q (2) | 186 | 4Q (1) | 361 | 4Q (1) | 364 |
| 135 | M-87 | MNW | 806070.22 | 399787.34 | 2480.64 | UZUU | No | Yes | 0.5 | 1Q (4) | 97.5 | 2Q (2) | 186 | 4Q (1) | 361 | 4Q (1) | 364 |
| 136 | M-88 | MNW | 806115.49 | 399950.7 | 2479.155 | UZUU | No | Yes | 0.75 | 1Q (4) | 96.5 | 2Q (2) | 196 | 4Q (1) | 361 | 4Q (1) | 364 |
| 137 | M-89 | MNW | 805765.23 | 399686.31 | 2476.685 | UZUU | No | Yes | 0.5 | 1Q (4) | 96 | 2Q (2) | 225 | 4Q (1) | 361 | 4Q (1) | 364 |
| 138 | M-90 | MNW | 806943.72 | 399554.56 | 2483.5 | UZUU | No | Yes | 0.75 | 2Q (2) | 188 | 3Q (1.33) | 251 | 4Q (1) | 361 | 4Q (1) | 364 |
| 139 | M-91 | MNW | 805928.95 | 400008.9 | 2477.6 | UZUU | No | Yes | 0.6667 | 1Q (4) | 99 | 4Q (1) | 397 | 4Q (1) | 361 | 4Q (1) | 364 |
| 140 | M-92 | MNW | 801112.5 | 401999.7 | 2459.465 | UZUU | No | No | 0.4 | 1Q (4) | 130.5 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 141 | M-93 | MNW | 801321.8 | 401824 | 2459.65 | UZUU | No | No | 0.3077 | 1Q (4) | 104 | 4Q (1) | 333 | 4Q (1) | 361 | 4Q (1) | 364 |
| 142 | M-94 | MNW | 801470.5 | 401936.9 | 2459.625 | UZUU | No | Yes | 0.5714 | 1Q (4) | 91 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 143 | M-95 | MNW | 801593.5 | 401978.5 | 2460.865 | UZUU | No | Yes | 0.7 | 2Q (2) | 161 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 144 | M-96 | MNW | 801306.5 | 402104.5 | 2459.22 | UZUU | No | No | 0.3636 | 1Q (4) | 132 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 145 | M-97 | MNW | 801152.5 | 402221.1 | 2459.53 | UZUU | No | No | 0.2727 | 1Q (4) | 94 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 146 | M-98 | MNW | 800899 | 402277.9 | 2462.78 | UZUU | No | Yes | 0.5 | 1Q (4) | 90.5 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 147 | M-99 | MNW | 802755 | 402340.41 | 2386.15 | UZUU | No | Yes | 0.6667 | 1Q (4) | 90.5 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 148 | P-02 | MNW | 798696.91 | 403195.46 | 2482.26 | SGZ | No | Yes | 1 | 2Q (2) | 182.5 | 2Q (2) | 169 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 149 | P-03 | MNW | 797776.32 | 402731.61 | 2472.67 | SGZ | No | No | 0.4444 | 2Q (2) | 184 | 4Q (1) | 368 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 150 | P-04 | MNW | 796841.42 | 403154.25 | 2470.265 | SGZ | No | No | 0.4286 | 2Q (2) | 212 | 4Q (1) | 357 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 151 | P-05 | MNW | 796793.61 | 401483.96 | 2473.43 | SGZ | Yes | Yes | 1 | 2Q (2) | 183 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 152 | P-06 | MNW | 796861.63 | 403178.14 | 2468.99 | SGZ | No | Yes | 0.6154 | 2Q (2) | 184 | 4Q (1) | 368 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 153 | P-08 | MNW | 799475.74 | 401112.48 | 2495.39 | SGZ | No | Yes | 0.6667 | 1Q (4) | 58 | 1Q (4) | 133 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 155 | R-07M | OBS | 798233.58 | 405965.41 | 2417.18 | LZ-UZLU | No | Yes | 1 | NA (NA) | NA | NA | NA | 4Q (1) | 364 | 4Q (1) | 364 |
| 156 | R-08M | OBS | 793914.89 | 405484.09 | 2456.48 | LZ-UZLU | No | Yes | 0.8889 | 4Q (1) | 365.5 | NA | NA | 4Q (1) | 364 | 4Q (1) | 364 |
| | | | | | | LZ- | | | | | | | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 157 | R-09M | OBS | 793975.88 | 403940.89 | 2446.55 | LZ-UZLU | No | Yes | 0.8889 | 4Q (1) | 365.5 | NA | NA | 4Q (1) | 364 | 4Q (1) | 364 |
| 158 | R-10M | OBS | 796298.89 | 402248.3 | 2431.63 | UZUU | No | Yes | 0.6364 | 2Q (2) | 186 | 9Q (0.44) | 850 | 4Q (1) | 361 | 4Q (1) | 364 |
| 159 | R-12M | OBS | 798985.19 | 401118.42 | 2445.04 | UZUU | No | Yes | 0.5 | 1Q (4) | 98 | 2Q (2) | 176 | 4Q (1) | 361 | 4Q (1) | 364 |
| 160 | R-13M | OBS | 800464.82 | 401328.26 | 2403.85 | LZ-UZLU | No | Yes | 0.8462 | 2Q (2) | 142 | 6Q (0.67) | 505 | 4Q (1) | 364 | 4Q (1) | 364 |
| 162 | R-14AM | OBS | 804212.03 | 401097.26 | 2497.73 | UZUU | No | Yes | 0.625 | 2Q (2) | 139.5 | 8Q (0.5) | 698 | 4Q (1) | 361 | 4Q (1) | 364 |
| 163 | S-10 | MNW | 798889.94 | 401153.24 | 2485.32 | SGZ | No | No | 0.3077 | 2Q (2) | 190 | 4Q (1) | 380 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 164 | S-21 | MNW | 799848.47 | 400926.1 | 2516.235 | SGZ | No | Yes | 0.6667 | 1Q (4) | 101 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 165 | S-23 | MNW | 798012.6 | 402369.62 | 2502.535 | SGZ | No | No | 0.3 | 6Q (0.6667) | 554 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 166 | S-24 | EXW | 796843.37 | 403109.4 | 2485.285 | SGZ | No | No | 0.25 | 2Q (2) | 185.5 | 1Q (4) | 56 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 167 | S-25 | EXW | 797138.26 | 402930.77 | 2498.7 | SGZ | No | No | 0.3333 | 1Q (4) | 93 | 1Q (4) | 114 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 169 | S-27 | EXW | 798183.66 | 402280.65 | 2493.38 | SGZ | No | No | 0 | 16Q (0.25) | 1417.5 | 3Q (1.33) | 229 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 170 | S-28 | EXW | 796880.39 | 402529.39 | 2477.14 | SGZ | No | Yes | 0.5 | 2Q (2) | 185.5 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 171 | S-29 | EXW | 797231.17 | 402264.65 | 2488.95 | SGZ | No | Yes | 0.5714 | 2Q (2) | 185 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 172 | S-30 | EXW | 797728.33 | 402085.57 | 2491.51 | SGZ | No | Yes | 0.5385 | 2Q (2) | 184 | 5Q (0.8) | 421 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 173 | S-31 | EXW | 798106.75 | 401867.56 | 2496.16 | SGZ | No | No | 0.2308 | 2Q (2) | 184 | 5Q (0.8) | 491 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 174 | S-32 | MNW | 796310.54 | 403029.62 | 2472.26 | SGZ | No | Yes | 0.8462 | 2Q (2) | 183.5 | 7Q (0.57) | 593 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 175 | S-33 | MNW | 796926.61 | 403610.68 | 2483.07 | SGZ | No | Yes | 1 | 2Q (2) | 184 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 176 | SF-05 | MNW | 796422.33 | 408286.04 | 2382.18 | LZ-UZLU | No | Yes | 0.6923 | 1Q (4) | 107.5 | 3Q (1.33) | 287 | 4Q (1) | 364 | 4Q (1) | 364 |
| 177 | SM-01B | MNW | 798666.55 | 401121.31 | 2471.245 | UZUU | No | Yes | 0.6667 | 10Q (0.4) | 913 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 178 | SM-02B | MNW | 798627.53 | 401120.78 | 2473.985 | UZUU | No | Yes | 0.625 | 4Q (1) | 364.5 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 179 | SM-03B | MNW | 798597.2 | 401120.51 | 2473.16 | UZUU | No | Yes | 0.8333 | 4Q (1) | 361 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 180 | SM-04B | MNW | 797558.88 | 402664.2 | 2474.245 | UZUU | No | No | 0.3333 | 3Q (1.3333) | 268.5 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 181 | SM-05B | MNW | 796907.25 | 402531.54 | 2481.22 | UZUU | No | No | 0 | NA (NA) | NA | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 182 | SR-01 | EXW | 799016.26 | 401571.71 | 2490.935 | SGZ | No | No | 0.25 | 2Q (2) | 182 | 5Q (0.8) | 416 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 183 | SR-02 | EXW | 799215.34 | 401703.41 | 2493.82 | SGZ | No | Yes | 0.6 | 2Q (2) | 181.5 | 8Q (0.5) | 679 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 184 | SR-03 | EXW | 799016.24 | 401975.85 | 2492.755 | SGZ | No | Yes | 0.5 | 2Q (2) | 209 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 185 | SR-04 | EXW | 798676.97 | 401576.52 | 2491.83 | SGZ | No | Yes | 0.5 | 2Q (2) | 186.5 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 186 | SR-05 | EXW | 798616.14 | 401975.03 | 2496.195 | SGZ | No | Yes | 0.5 | 2Q (2) | 185 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 187 | SR-07 | EXW | 796789.97 | 403112.9 | 2490.255 | SGZ | No | Yes | 0.5 | 2Q (2) | 182 | 5Q (0.8) | 489 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 188 | SR-08 | EXW | 796803.85 | 402761.87 | 2490.08 | SGZ | No | No | 0.25 | 2Q (2) | 185.5 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 189 | SR-09 | EXW | 798969.25 | 402327.03 | 2495.015 | SGZ | No | Yes | 0.75 | 4Q (1) | 371 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 190 | SR-10 | EXW | 799416.69 | 401118.22 | 2494.71 | SGZ | No | Yes | 0.5 | 2Q (2) | 182 | 5Q (0.8) | 418 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 191 | SR-11 | EXW | 797670.22 | 401671.66 | 2505.98 | SGZ | No | Yes | 0.5 | NA (NA) | NA | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 192 | SR-12 | EXW | 798078.64 | 402074.64 | 2496.145 | SGZ | No | No | 0.1 | 2Q (2) | 184 | 5Q (0.8) | 453 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 193 | SR-13 | EXW | 799014.24 | 401127.19 | 2493.645 | SGZ | No | No | 0.1 | 2Q (2) | 185.5 | 5Q (0.8) | 440 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 194 | SR-14 | EXW | 798676.85 | 401121.38 | 2492.49 | SGZ | No | Yes | 0.5 | 2Q (2) | 189 | 6Q (0.67) | 569 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 195 | SR-15 | EXW | 797917.85 | 402374.93 | 2495.295 | SGZ | No | No | 0.3333 | 2Q (2) | 190 | 6Q (0.67) | 507 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 196 | SR-16 | EXW | 797956.36 | 402641.13 | 2497.605 | SGZ | No | Yes | 0.6 | 2Q (2) | 184 | 6Q (0.67) | 532 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 197 | SR-17 | EXW | 797618.21 | 402344.86 | 2493.67 | SGZ | No | Yes | 0.5 | 2Q (2) | 181.5 | 3Q (1.33) | 291 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 198 | SR-18 | EXW | 798783.43 | 401325.53 | 2493.91 | SGZ | No | Yes | 0.5 | 2Q (2) | 197 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 199 | SR-19 | EXW | 799212.29 | 401337.99 | 2495.46 | SGZ | No | No | 0.2 | 2Q (2) | 183 | 4Q (1) | 372 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 200 | SR-20 | EXW | 798851.48 | 400920.02 | 2489.95 | SGZ | No | Yes | 0.5 | 2Q (2) | 182 | 4Q (1) | 353 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 201 | SR-21 | EXW | 799223.05 | 400938.53 | 2490.735 | SGZ | No | No | 0.4 | 2Q (2) | 182 | 4Q (1) | 335 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 202 | SR-22 | EXW | 799815.85 | 401144.46 | 2498.34 | SGZ | No | Yes | 0.875 | 2Q (2) | 189 | 4Q (1) | 384 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 203 | SR-23 | EXW | 798215.35 | 401083.47 | 2491.595 | SGZ | No | Yes | 0.8 | 2Q (2) | 182 | 6Q (0.67) | 506 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 204 | SR-25 | EXW | 799416.09 | 401564.36 | 2495.995 | SGZ | No | Yes | 0.5 | 2Q (2) | 186 | 8Q (0.5) | 744 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 205 | SR-26 | EXW | 799611.93 | 401349.78 | 2497.235 | SGZ | No | Yes | 0.7 | 2Q (2) | 181.5 | 5Q (0.8) | 465 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 206 | SR-27 | EXW | 799427.93 | 402019.57 | 2498.915 | SGZ | No | Yes | 0.5 | 2Q (2) | 185.5 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 207 | SR-28 | EXW | 796811.81 | 402480.35 | 2496.885 | SGZ | No | Yes | 0.5 | 2Q (2) | 183 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 208 | SR-29 | EXW | 796803.4 | 402939.93 | 2490.785 | SGZ | No | No | 0.25 | 2Q (2) | 185.5 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 209 | SR-30 | EXW | 799606.91 | 400946.99 | 2499.465 | SGZ | No | Yes | 0.6 | 2Q (2) | 182 | 5Q (0.8) | 467 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 210 | SR-31 | EXW | 799019.84 | 400599.01 | 2491.45 | SGZ | No | Yes | 1 | 2Q (2) | 182 | 6Q (0.67) | 572 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 211 | SR-32 | EXW | 799417.19 | 400605.67 | 2498.2 | SGZ | No | No | 0.25 | 2Q (2) | 186 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |

*Sample Elevation*
Approximate elevation at which sample measurements are collected.
*Vertical Zone*
Designated aquifer horizon in which well screen is located.
*Protected Status*
Binary flag designating whether or not well is subject to spatial optimization; 1 = protected from optimization, 0 = eligible for optimization.
*Critical Status*
Binary flag designating whether or not well location is statisticall redundant to current network; 1 = critical, non-redundant, 0 = redundant, non-essential.
*Baseline Frequency (per year)*
Approximate current sampling frequency, rounded to nearest quarter; e.g., 3Q = one sample every 3

Approximate current sampling interval in days, based on averaging lapsed intervals between distinct sampling events; NA = not enough data to compute.
*Well-Specific Optimal Frequency (per year)*
Approximate optimized sampling frequency, rounded to nearest quarter; e.g., 3Q = one sample every 3 quarters; per year = optimal number of samples collected per annum.
*Well-Specific Optimal Interval*
Approximate optimized sampling interval in days, based on either iterative thinning or temporal variogram range; NA = not enough data to compute.

# GTS New Location Report

## Summary of Suggested New Well Locations

Project = afp44_v1_100209
AFIID/Site = NA
Date Completed = August 5, 2010
Author = MacStat Consulting/Kirk Cameron

| Vertical Zone | Easting | Northing | Search Radius | Wells Within Radius | Quantile Score | CV Score |
|---|---|---|---|---|---|---|
| UZUU | 800741.019773 | 399622.003955 | 1292.474412 | 2 | 0.829183 | 9.537914 |
| UZUU | 802518.622936 | 399622.003955 | 1292.474412 | 2 | 0.801875 | 9.28397 |
| UZUU | 799852.218191 | 404954.813445 | 1292.474412 | 2 | 0.781969 | 1.683671 |
| UZUU | 801629.821355 | 404954.813445 | 1292.474412 | 0 | 0.770044 | 1.622916 |
| UZUU | 792741.805536 | 404954.813445 | 1292.474412 | 1 | 0.781334 | 1.101643 |
| UZUU | 800741.019773 | 407621.218191 | 1292.474412 | 0 | 0.768863 | 0.848486 |
| SGZ | 798074.615027 | 403177.210282 | 1292.474412 | 18 | 0.752983 | 1.252024 |
| SGZ | 798074.615027 | 401399.607118 | 1292.474412 | 31 | 0.769658 | 1.189167 |
| LZ-UZLU | 798074.615027 | 401399.607118 | 1292.474412 | 1 | 0.769814 | 0.569841 |
| LZ-UZLU | 806073.829264 | 400510.805536 | 1292.474412 | 1 | 0.788651 | 0.458997 |
| LZ-UZLU | 801629.821355 | 397844.400791 | 1292.474412 | 0 | 0.751219 | 0.458458 |

*Search Radius*
Radius of uncertainty search.
*Wells Within Radius*
Number of current wells located within search radius distance of proposed location.
*Quantile Score*
Estimated average percentile of site concentrations within search radius distance of proposed location.
*CV Score*
Estimated average coefficient of variation within search radius distance of proposed location.

## AFP44 OPTIMIZATION RESULTS — DATABASE VERSION 2

# GTS Optimized Network Status Report

### Summary of Optimized Status for Each Well as Identified by GTS using the NPL Dataset

Project = afp44_v2_100309
AFIID/Site = NA
Date Completed = August 5, 2010
Author = MacStat Consulting, Ltd/Kirk Cameron

### Using Iterative Thinning

| GTS Well ID | Loc ID | Well Type | Easting | Northing | Sample Elevation | Vertical Zone | Protected Status | Critical Status | Critical Index | Baseline Frequency (per year) | Baseline Interval (days) | Well-Specific Optimal Frequency (per year) | Well-Specific Optimal Interval (days) | Zone-Based Optimal Frequency (per year) | Zone-Based Optimal Interval (days) | Site-Based Optimal Frequency (per year) | Site-Based Optimal Interval (days) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | B-01 | MNW | 798056.54 | 401594.26 | 2491.19 | SGZ | No | Yes | 0.6 | 22Q (0.1818) | 1967 | 2Q (2) | 194 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 2 | B-02 | MNW | 798257.19 | 401530.72 | 2495.675 | SGZ | No | Yes | 0.6 | 22Q (0.1818) | 1967 | 2Q (2) | 194 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 3 | B-03 | MNW | 798376.18 | 401421.12 | 2489.515 | SGZ | No | Yes | 0.6 | 22Q (0.1818) | 1966.5 | 3Q (1.33) | 310 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 4 | B-09 | MNW | 799076.39 | 401722.9 | 2495.02 | SGZ | No | Yes | 0.6 | 22Q (0.1818) | 1944 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 5 | CRED_UN | MNW | 797533.99 | 403467.37 | 2417.61 | LZ-UZLU | No | Yes | 0.7222 | 1Q (4) | 99.5 | 4Q (1) | 354 | 4Q (1) | 364 | 4Q (1) | 364 |
| 6 | E-01 | EXW | 799007.39 | 403182.99 | 2424.87 | LZ-UZLU | No | No | 0.3889 | 1Q (4) | 105 | 5Q (0.8) | 480 | 4Q (1) | 364 | 4Q (1) | 364 |
| 7 | E-02 | EXW | 798073.88 | 403184.48 | 2435.48 | LZ-UZLU | No | No | 0.4545 | 1Q (4) | 90 | 5Q (0.8) | 480 | 4Q (1) | 364 | 4Q (1) | 364 |
| 8 | E-03 | EXW | 797547.8 | 403926.13 | 2456.88 | LZ-UZLU | No | Yes | 0.5909 | 1Q (4) | 89.5 | 5Q (0.8) | 480 | 4Q (1) | 364 | 4Q (1) | 364 |
| 9 | E-04 | EXW | 796273.11 | 404182.38 | 2443.98 | LZ-UZLU | No | Yes | 0.5455 | 1Q (4) | 89 | 5Q (0.8) | 416 | 4Q (1) | 364 | 4Q (1) | 364 |
| 10 | E-04M | OBS | 796268.22 | 404169.48 | 2403.74 | LZ-UZLU | No | No | 0.3333 | NA (NA) | NA | NA | NA | 4Q (1) | 364 | 4Q (1) | 364 |
| 11 | E-05 | EXW | 797073.56 | 405795.6 | 2465.53 | LZ-UZLU | No | Yes | 0.6875 | 2Q (2) | 141 | 1Q (4) | 103 | 4Q (1) | 364 | 4Q (1) | 364 |
| 12 | E-06 | IJW | 795211.8 | 405885.1 | 2427.955 | LZ-UZLU | No | Yes | 0.75 | 1Q (4) | 91 | 3Q (1.33) | 278 | 4Q (1) | 364 | 4Q (1) | 364 |
| 13 | E-09 | IJW | 794058 | 408028 | 2435.03 | LZ-UZLU | No | Yes | 0.6667 | 1Q (4) | 91 | 2Q (2) | 190 | 4Q (1) | 364 | 4Q (1) | 364 |
| 14 | E-09R | EXW | 794742.12 | 407666.34 | 2418.1 | LZ-UZLU | No | No | 0.3333 | NA (NA) | NA | NA | NA | 4Q (1) | 364 | 4Q (1) | 364 |
| 15 | E-10 | EXW | 805750.82 | 399878.85 | 2489.12 | UZUU | No | Yes | 0.6471 | 1Q (4) | 89 | 4Q (1) | 338 | 4Q (1) | 361 | 4Q (1) | 364 |
| 16 | E-12 | EXW | 803038.67 | 402196.53 | 2483.09 | UZUU | No | Yes | 0.7273 | 1Q (4) | 93 | 4Q (1) | 372 | 4Q (1) | 361 | 4Q (1) | 364 |
| 17 | E-13 | EXW | 801723.99 | 403018.54 | 2400.64 | LZ-UZLU | No | Yes | 0.6364 | 1Q (4) | 91 | 3Q (1.33) | 291 | 4Q (1) | 364 | 4Q (1) | 364 |
| 18 | E-14 | EXW | 801158.66 | 402109.87 | 2435.07 | UZUU | No | Yes | 0.55 | 1Q (4) | 92 | 5Q (0.8) | 491 | 4Q (1) | 361 | 4Q (1) | 364 |
| 19 | E-15 | EXW | 800300.77 | 402100.36 | 2461.04 | LZ-UZLU | No | Yes | 0.6364 | 1Q (4) | 91 | 5Q (0.8) | 416 | 4Q (1) | 364 | 4Q (1) | 364 |
| 20 | E-16 | EXW | 806475.42 | 399369.86 | 2521.51 | UZUU | No | Yes | 0.75 | 1Q (4) | 91 | 4Q (1) | 390 | 4Q (1) | 361 | 4Q (1) | 364 |
| 21 | E-17 | EXW | 797288.33 | 402072.31 | 2451.45 | LZ-UZLU | No | Yes | 0.6818 | 1Q (4) | 89 | 5Q (0.8) | 407 | 4Q (1) | 364 | 4Q (1) | 364 |
| 22 | E-18 | EXW | 800167.13 | 402623.36 | 2451.225 | LZ-UZLU | No | Yes | 0.5 | 1Q (4) | 91 | 5Q (0.8) | 416 | 4Q (1) | 364 | 4Q (1) | 364 |
| 23 | E-19 | EXW | 801169.92 | 401892.96 | 2542.655 | UZUU | No | Yes | 0.6111 | 1Q (4) | 91 | 5Q (0.8) | 416 | 4Q (1) | 361 | 4Q (1) | 364 |
| 24 | E-20 | EXW | 806333.62 | 399981.5 | 2477.6 | LZ-UZLU | No | Yes | 0.8571 | 1Q (4) | 91 | 5Q (0.8) | 416 | 4Q (1) | 364 | 4Q (1) | 364 |
| 25 | E-21 | EXW | 801287.98 | 401954.74 | 2466.7 | UZUU | No | No | 0.2222 | 1Q (4) | 92 | 5Q (0.8) | 491 | 4Q (1) | 361 | 4Q (1) | 364 |
| 26 | E-22 | EXW | 806319.52 | 399642.19 | 2490.17 | UZUU | No | No | 0.4 | 1Q (4) | 102 | 1Q (4) | 118 | 4Q (1) | 361 | 4Q (1) | 364 |
| 27 | E-23 | EXW | 798497.96 | 402380.08 | 2384.075 | UZUU | No | Yes | 0.5455 | 1Q (4) | 92 | 5Q (0.8) | 421 | 4Q (1) | 361 | 4Q (1) | 364 |
| 28 | E-24 | EXW | 796879.64 | 403145.68 | 2388.575 | LZ-UZLU | No | No | 0.4545 | 1Q (4) | 90 | 4Q (1) | 360 | 4Q (1) | 364 | 4Q (1) | 364 |
| 29 | EL-01 | EXW | 803442.01 | 400602.03 | 2342.33 | LZ-UZLU | No | Yes | 0.7857 | 1Q (4) | 96 | 6Q (0.67) | 504 | 4Q (1) | 364 | 4Q (1) | 364 |
| 30 | EL-02 | EXW | 801093.21 | 403218.95 | 2351.8 | LZ-UZLU | No | Yes | 0.7727 | 1Q (4) | 91 | 5Q (0.8) | 416 | 4Q (1) | 364 | 4Q (1) | 364 |
| 31 | EL-03 | EXW | 799307.61 | 403114.85 | 2275.94 | LZ-UZLU | No | Yes | 0.6364 | 1Q (4) | 91 | 4Q (1) | 364 | 4Q (1) | 364 | 4Q (1) | 364 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 32 | EL-04 | EXW | 796985.35 | 403395.42 | 2222.82 | LZ-UZLU | No | No | 0.4737 | 1Q (4) | 89 | 8Q (0.5) | 712 | 4Q (1) | 364 | 4Q (1) | 364 |
| 33 | EPA-01 | MNW | 795412.13 | 403906.29 | 2430.86 | LZ-UZLU | No | Yes | 0.8182 | 1Q (4) | 91 | 5Q (0.8) | 416 | 4Q (1) | 364 | 4Q (1) | 364 |
| 34 | EPA-02 | MNW | 796632.8 | 404558.26 | 2437.54 | LZ-UZLU | No | Yes | 0.6111 | 1Q (4) | 102 | 5Q (0.8) | 453 | 4Q (1) | 364 | 4Q (1) | 364 |
| 35 | EPA-02A | MNW | 796647.63 | 404489.82 | 2222.25 | LZ-UZLU | No | Yes | 0.5 | 1Q (4) | 98 | 4Q (1) | 348 | 4Q (1) | 364 | 4Q (1) | 364 |
| 36 | EPA-03 | MNW | 798228.45 | 405950.46 | 2385.04 | LZ-UZLU | Yes | Yes | 1 | 1Q (4) | 99 | 3Q (1.33) | 282 | 4Q (1) | 364 | 4Q (1) | 364 |
| 37 | EPA-04 | MNW | 794893.49 | 405309.34 | 2431.72 | LZ-UZLU | No | Yes | 0.5 | 1Q (4) | 103 | 3Q (1.33) | 288 | 4Q (1) | 364 | 4Q (1) | 364 |
| 38 | EPA-05 | MNW | 795813.2 | 406960.83 | 2434.44 | LZ-UZLU | No | Yes | 0.6923 | 1Q (4) | 104 | 5Q (0.8) | 475 | 4Q (1) | 364 | 4Q (1) | 364 |
| 39 | M-01A | MNW | 804027.27 | 403174.06 | 2442.25 | LZ-UZLU | No | Yes | 0.7333 | 4Q (1) | 361 | NA | NA | 4Q (1) | 364 | 4Q (1) | 364 |
| 40 | M-01B | MNW | 804048.21 | 403173.35 | 2292.67 | LZ-UZLU | No | No | 0.2 | 3Q (1.3333) | 266 | NA | NA | 4Q (1) | 364 | 4Q (1) | 364 |
| 41 | M-02A | EXW | 798123.41 | 402318.17 | 2498.74 | SGZ | No | No | 0 | NA (NA) | NA | 5Q (0.8) | 448 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 42 | M-02B | MNW | 798108.33 | 402328.7 | 2449.37 | UZUU | No | Yes | 0.6667 | 1Q (4) | 106 | 4Q (1) | 377 | 4Q (1) | 361 | 4Q (1) | 364 |
| 43 | M-02C | MNW | 798103.46 | 402350.52 | 2124.41 | LZ-UZLU | No | Yes | 0.5333 | 1Q (4) | 105 | 3Q (1.33) | 268 | 4Q (1) | 364 | 4Q (1) | 364 |
| 44 | M-03A | MNW | 801465.81 | 402946.47 | 2459.71 | LZ-UZLU | No | Yes | 0.6667 | 1Q (4) | 103 | 5Q (0.8) | 412 | 4Q (1) | 364 | 4Q (1) | 364 |
| 45 | M-03B | MNW | 801466.3 | 402974.67 | 2325.38 | LZ-UZLU | No | Yes | 0.5556 | 1Q (4) | 95.5 | 3Q (1.33) | 278 | 4Q (1) | 364 | 4Q (1) | 364 |
| 46 | M-05 | MNW | 801029.48 | 402082.38 | 2470.97 | UZUU | No | No | 0.3333 | 1Q (4) | 91 | 3Q (1.33) | 271 | 4Q (1) | 361 | 4Q (1) | 364 |
| 47 | M-06 | MNW | 799826.19 | 403798.37 | 2464.92 | UZUU | No | Yes | 0.7895 | 1Q (4) | 105 | 4Q (1) | 389 | 4Q (1) | 361 | 4Q (1) | 364 |
| 48 | M-07 | MNW | 798667.11 | 403188.45 | 2460.01 | LZ-UZLU | No | No | 0.4737 | 1Q (4) | 104 | 5Q (0.8) | 416 | 4Q (1) | 364 | 4Q (1) | 364 |
| 49 | M-08 | MNW | 797792.02 | 402711.76 | 2451.83 | UZUU | No | Yes | 0.6111 | 1Q (4) | 92 | 4Q (1) | 368 | 4Q (1) | 361 | 4Q (1) | 364 |
| 50 | M-09 | MNW | 799305.28 | 401745.31 | 2454.91 | LZ-UZLU | No | Yes | 0.7778 | 1Q (4) | 92.5 | 4Q (1) | 329 | 4Q (1) | 364 | 4Q (1) | 364 |
| 51 | M-10 | MNW | 798188.37 | 401559.72 | 2445.59 | UZUU | No | Yes | 0.5556 | 1Q (4) | 92 | 3Q (1.33) | 268 | 4Q (1) | 361 | 4Q (1) | 364 |
| 52 | M-100 | MNW | 801104.3 | 402435.3 | 2463.47 | UZUU | No | Yes | 0.5 | 1Q (4) | 94.5 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 53 | M-101 | MNW | 800870.4 | 402568.8 | 2463.19 | UZUU | No | No | 0.4167 | 1Q (4) | 97.5 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 54 | M-102 | MNW | 801472 | 402472 | 2464.345 | UZUU | No | No | 0.3333 | 1Q (4) | 94 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 55 | M-103 | MNW | 802787 | 402313.9 | 2473.985 | UZUU | No | Yes | 0.6667 | 1Q (4) | 92.5 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 56 | M-104 | MNW | 801202.3 | 402612.3 | 2465.66 | UZUU | No | Yes | 0.6 | 1Q (4) | 134 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 57 | M-105 | MNW | 800883.5 | 402775.7 | 2461.825 | UZUU | No | Yes | 0.5625 | 2Q (2) | 141 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 58 | M-106M | MNW | 802822.32 | 402286.36 | 2477.54 | UZUU | No | Yes | 0.75 | NA (NA) | NA | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 59 | M-11 | MNW | 800933.91 | 403231.42 | 2457.82 | LZ-UZLU | No | Yes | 0.7222 | 1Q (4) | 117 | 5Q (0.8) | 416 | 4Q (1) | 364 | 4Q (1) | 364 |
| 60 | M-12A | MNW | 796892.76 | 403187.78 | 2433.07 | UZUU | No | Yes | 0.7222 | 1Q (4) | 103 | 4Q (1) | 330 | 4Q (1) | 361 | 4Q (1) | 364 |
| 61 | M-12B | MNW | 796951.98 | 403189.67 | 2294.52 | LZ-UZLU | No | Yes | 0.6667 | 1Q (4) | 96 | 3Q (1.33) | 307 | 4Q (1) | 364 | 4Q (1) | 364 |
| 62 | M-13 | MNW | 796877.98 | 402300.19 | 2447.17 | UZUU | No | Yes | 0.6667 | 1Q (4) | 124 | 4Q (1) | 361 | 4Q (1) | 361 | 4Q (1) | 364 |
| 63 | M-14 | MNW | 796822.16 | 401070.61 | 2442.28 | LZ-UZLU | No | Yes | 0.8125 | 1Q (4) | 99 | 4Q (1) | 402 | 4Q (1) | 364 | 4Q (1) | 364 |
| 64 | M-15 | MNW | 801484.8 | 399684.67 | 2522.91 | LZ-UZLU | No | Yes | 1 | 1Q (4) | 131.5 | 4Q (1) | 324 | 4Q (1) | 364 | 4Q (1) | 364 |
| 65 | M-16 | MNW | 803566.54 | 400632.94 | 2456.19 | LZ-UZLU | No | Yes | 0.7059 | 1Q (4) | 99.5 | 3Q (1.33) | 229 | 4Q (1) | 364 | 4Q (1) | 364 |
| 66 | M-17 | MNW | 805014.84 | 400443.98 | 2503.16 | UZUU | No | Yes | 0.8889 | 1Q (4) | 91 | 3Q (1.33) | 291 | 4Q (1) | 361 | 4Q (1) | 364 |
| 67 | M-18 | MNW | 806296.77 | 399751.23 | 2498.26 | UZUU | No | Yes | 0.5789 | 1Q (4) | 81 | 4Q (1) | 316 | 4Q (1) | 361 | 4Q (1) | 364 |
| 68 | M-19 | MNW | 803861.53 | 398687.9 | 2466.81 | UZUU | No | Yes | 0.8235 | 1Q (4) | 93 | 3Q (1.33) | 304 | 4Q (1) | 361 | 4Q (1) | 364 |
| 69 | M-20 | MNW | 802918.35 | 402393.23 | 2480.08 | LZ-UZLU | No | Yes | 0.7778 | 1Q (4) | 92 | 3Q (1.33) | 294 | 4Q (1) | 364 | 4Q (1) | 364 |
| 70 | M-21 | MNW | 808528.71 | 398208.72 | 2471.13 | LZ-UZLU | No | Yes | 0.7692 | 4Q (1) | 358.5 | NA | NA | 4Q (1) | 364 | 4Q (1) | 364 |
| 71 | M-22A | MNW | 796928.21 | 399116.38 | 2444.02 | LZ-UZLU | No | Yes | 0.5 | 4Q (1) | 317.5 | NA | NA | 4Q (1) | 364 | 4Q (1) | 364 |
| 72 | M-22B | MNW | 796943.91 | 399069.51 | 2251.64 | LZ-UZLU | No | Yes | 0.5 | 4Q (1) | 317 | NA | NA | 4Q (1) | 364 | 4Q (1) | 364 |
| 73 | M-23 | MNW | 800053.31 | 403231.67 | 2434.53 | LZ-UZLU | No | No | 0.4444 | 1Q (4) | 106 | 5Q (0.8) | 424 | 4Q (1) | 364 | 4Q (1) | 364 |
| 74 | M-24A | MNW | 799369.12 | 400532.94 | 2441.235 | UZUU | No | Yes | 0.7647 | 1Q (4) | 120 | 4Q (1) | 320 | 4Q (1) | 361 | 4Q (1) | 364 |
| 75 | M-24B | MNW | 799423.64 | 400552.58 | 2328.565 | LZ-UZLU | No | Yes | 0.8 | 1Q (4) | 91.5 | 4Q (1) | 329 | 4Q (1) | 364 | 4Q (1) | 364 |
| 76 | M-25 | MNW | 801509.92 | 401122.49 | 2451.78 | UZUU | No | Yes | 0.7778 | 1Q (4) | 104 | 4Q (1) | 381 | 4Q (1) | 361 | 4Q (1) | 364 |
| 77 | M-26 | MNW | 803511.15 | 400612.14 | 2255.15 | LZ-UZLU | No | No | 0.4615 | 1Q (4) | 94.5 | 3Q (1.33) | 264 | 4Q (1) | 364 | 4Q (1) | 364 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 78 | M-27 | MNW | 805921.77 | 399978.43 | 2319.36 | LZ-UZLU | No | No | 0.4615 | 1Q (4) | 98.5 | 10Q (0.4) | 922 | 4Q (1) | 364 | 4Q (1) | 364 |
| 79 | M-28 | MNW | 804974.79 | 401904.79 | 2477.84 | LZ-UZLU | No | Yes | 0.75 | 2Q (2) | 178 | 6Q (0.67) | 518 | 4Q (1) | 364 | 4Q (1) | 364 |
| 80 | M-29 | MNW | 799663.69 | 403685.67 | 2306.6 | LZ-UZLU | No | Yes | 0.7222 | 1Q (4) | 95.5 | 2Q (2) | 180 | 4Q (1) | 364 | 4Q (1) | 364 |
| 81 | M-30 | MNW | 802282.99 | 403454.55 | 2452.3 | LZ-UZLU | No | Yes | 0.6316 | 1Q (4) | 127 | 14Q (0.29) | 1270 | 4Q (1) | 364 | 4Q (1) | 364 |
| 82 | M-31 | MNW | 800224.97 | 405337.2 | 2442.61 | UZUU | No | Yes | 0.8462 | 4Q (1) | 362.5 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 83 | M-32 | MNW | 798522.44 | 404841.11 | 2452.61 | LZ-UZLU | No | Yes | 0.7857 | 1Q (4) | 95 | 4Q (1) | 348 | 4Q (1) | 364 | 4Q (1) | 364 |
| 84 | M-33 | MNW | 803164.27 | 404469.49 | 2446.91 | UZUU | No | Yes | 0.8571 | 4Q (1) | 362 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 85 | M-34 | MNW | 796597.51 | 405953.88 | 2421.43 | UZUU | No | Yes | 0.6667 | 1Q (4) | 87 | 2Q (2) | 173 | 4Q (1) | 361 | 4Q (1) | 364 |
| 86 | M-35 | MNW | 798091.64 | 407948.44 | 2385.24 | LZ-UZLU | No | Yes | 0.8667 | 1Q (4) | 102 | 4Q (1) | 349 | 4Q (1) | 364 | 4Q (1) | 364 |
| 87 | M-36 | MNW | 795350.73 | 408364.35 | 2419.47 | LZ-UZLU | No | Yes | 0.7857 | 1Q (4) | 98 | 3Q (1.33) | 241 | 4Q (1) | 364 | 4Q (1) | 364 |
| 88 | M-37 | MNW | 793518.41 | 406853.41 | 2420.79 | LZ-UZLU | No | Yes | 0.6875 | 4Q (1) | 364 | 12Q (0.33) | 1059 | 4Q (1) | 364 | 4Q (1) | 364 |
| 89 | M-38 | MNW | 793192.56 | 404197.61 | 2433.37 | LZ-UZLU | No | Yes | 0.8667 | 4Q (1) | 367 | NA | NA | 4Q (1) | 364 | 4Q (1) | 364 |
| 90 | M-39 | MNW | 795046.48 | 401577.17 | 2440.03 | LZ-UZLU | No | Yes | 0.8667 | 4Q (1) | 364 | 32Q (0.12) | 2912 | 4Q (1) | 364 | 4Q (1) | 364 |
| 91 | M-40 | MNW | 795219.91 | 405888.09 | 2417.89 | LZ-UZLU | No | Yes | 0.5 | 1Q (4) | 94 | 3Q (1.33) | 256 | 4Q (1) | 364 | 4Q (1) | 364 |
| 92 | M-41 | MNW | 800165.75 | 402424.05 | 2459.84 | LZ-UZLU | No | Yes | 0.5556 | 1Q (4) | 96 | 4Q (1) | 341 | 4Q (1) | 364 | 4Q (1) | 364 |
| 93 | M-42 | MNW | 801761.55 | 400521.14 | 2470.19 | UZUU | No | Yes | 1 | NA (NA) | NA | 4Q (1) | 348 | 4Q (1) | 361 | 4Q (1) | 364 |
| 94 | M-43 | MNW | 799925.69 | 400144.58 | 2469.69 | UZUU | No | Yes | 1 | NA (NA) | NA | 4Q (1) | 347 | 4Q (1) | 361 | 4Q (1) | 364 |
| 95 | M-44 | MNW | 800920.83 | 400916.07 | 2461.49 | UZUU | No | Yes | 1 | NA (NA) | NA | 4Q (1) | 329 | 4Q (1) | 361 | 4Q (1) | 364 |
| 96 | M-45 | MNW | 800059.53 | 401776.85 | 2456.54 | UZUU | No | Yes | 1 | 8Q (0.5) | 746 | 15Q (0.27) | 1365 | 4Q (1) | 361 | 4Q (1) | 364 |
| 97 | M-46 | MNW | 799773.86 | 401768.31 | 2447.3 | UZUU | No | Yes | 0.65 | 2Q (2) | 174 | 4Q (1) | 398 | 4Q (1) | 361 | 4Q (1) | 364 |
| 98 | M-47 | MNW | 799502.89 | 401760.67 | 2451.72 | UZUU | No | Yes | 0.5333 | 2Q (2) | 175 | 4Q (1) | 329 | 4Q (1) | 361 | 4Q (1) | 364 |
| 99 | M-48 | MNW | 799184.13 | 401750.74 | 2460.96 | UZUU | No | No | 0.4706 | 2Q (2) | 177 | 9Q (0.44) | 805 | 4Q (1) | 361 | 4Q (1) | 364 |
| 100 | M-49 | MNW | 798879.76 | 401741.91 | 2458.58 | UZUU | No | Yes | 0.8333 | 1Q (4) | 100 | 1Q (4) | 131 | 4Q (1) | 361 | 4Q (1) | 364 |
| 101 | M-50 | MNW | 798631.49 | 401733.56 | 2459.2 | UZUU | No | Yes | 0.5789 | 2Q (2) | 182 | 4Q (1) | 388 | 4Q (1) | 361 | 4Q (1) | 364 |
| 102 | M-51 | MNW | 798639.73 | 401443.8 | 2460.03 | UZUU | No | Yes | 0.6923 | 2Q (2) | 181 | 5Q (0.8) | 446 | 4Q (1) | 361 | 4Q (1) | 364 |
| 103 | M-52 | MNW | 800277.05 | 401993.78 | 2446.53 | UZUU | No | Yes | 0.5 | 5Q (0.8) | 430.5 | 8Q (0.5) | 689 | 4Q (1) | 361 | 4Q (1) | 364 |
| 104 | M-53 | MNW | 800696.91 | 402059.48 | 2447.7 | UZUU | No | No | 0.4286 | 2Q (2) | 169 | 4Q (1) | 393 | 4Q (1) | 361 | 4Q (1) | 364 |
| 105 | M-54 | MNW | 801220.42 | 401477.74 | 2452.7 | UZUU | No | Yes | 1 | NA (NA) | NA | 4Q (1) | 348 | 4Q (1) | 361 | 4Q (1) | 364 |
| 106 | M-55A | MNW | 800850.73 | 398052.71 | 2444.74 | UZUU | No | Yes | 0.7333 | 1Q (4) | 95 | 3Q (1.33) | 270 | 4Q (1) | 361 | 4Q (1) | 364 |
| 107 | M-56 | MNW | 798642.66 | 398017.7 | 2450.425 | LZ-UZLU | No | Yes | 1 | 1Q (4) | 91 | 2Q (2) | 225 | 4Q (1) | 364 | 4Q (1) | 364 |
| 108 | M-57 | MNW | 799437.86 | 400468.8 | 2500.935 | SGZ | No | Yes | 1 | 2Q (2) | 191 | 3Q (1.33) | 283 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 109 | M-58 | MNW | 804077.54 | 398087.25 | 2455.84 | UZUU | No | No | 0.4 | 1Q (4) | 90 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 110 | M-59 | MNW | 803675 | 398209.64 | 2446.625 | LZ-UZLU | No | Yes | 0.8 | 1Q (4) | 90 | NA | NA | 4Q (1) | 364 | 4Q (1) | 364 |
| 111 | M-60 | MNW | 803853.79 | 402953.58 | 2457.005 | LZ-UZLU | No | Yes | 0.6923 | 1Q (4) | 95 | 6Q (0.67) | 551 | 4Q (1) | 364 | 4Q (1) | 364 |
| 112 | M-61 | MNW | 804183.14 | 398022.36 | 2443.67 | LZ-UZLU | No | Yes | 0.6154 | 1Q (4) | 100 | 4Q (1) | 396 | 4Q (1) | 364 | 4Q (1) | 364 |
| 113 | M-62 | MNW | 804182.26 | 398039.18 | 2474.21 | UZUU | No | No | 0.4 | 1Q (4) | 90 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 114 | M-63 | MNW | 804196.88 | 398032.44 | 2492.185 | UZUU | No | No | 0.3077 | 1Q (4) | 98.5 | 3Q (1.33) | 244 | 4Q (1) | 361 | 4Q (1) | 364 |
| 115 | M-64 | MNW | 806348.31 | 399856.59 | 2466.105 | UZUU | No | No | 0.4286 | 1Q (4) | 97 | 3Q (1.33) | 230 | 4Q (1) | 361 | 4Q (1) | 364 |
| 116 | M-65 | MNW | 806352.62 | 399885.98 | 2483.33 | UZUU | No | Yes | 0.5 | 1Q (4) | 97 | 3Q (1.33) | 239 | 4Q (1) | 361 | 4Q (1) | 364 |
| 117 | M-66 | MNW | 806349.84 | 399871.75 | 2499.415 | UZUU | No | Yes | 0.5 | 6Q (0.6667) | 535.5 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 118 | M-67 | MNW | 801183.91 | 401972.44 | 2399.57 | LZ-UZLU | No | Yes | 0.8 | 1Q (4) | 96 | 3Q (1.33) | 311 | 4Q (1) | 364 | 4Q (1) | 364 |
| 119 | M-68 | MNW | 801209.71 | 401947.07 | 2442.505 | UZUU | No | Yes | 0.5 | 1Q (4) | 96.5 | 3Q (1.33) | 257 | 4Q (1) | 361 | 4Q (1) | 364 |
| 120 | M-69 | MNW | 801186.42 | 401922.29 | 2469.515 | UZUU | No | Yes | 0.5833 | 1Q (4) | 94 | 3Q (1.33) | 251 | 4Q (1) | 361 | 4Q (1) | 364 |
| 121 | M-70 | MNW | 804949.23 | 399606.17 | 2473.685 | UZUU | No | Yes | 0.7692 | 1Q (4) | 109 | 4Q (1) | 326 | 4Q (1) | 361 | 4Q (1) | 364 |
| 122 | M-71 | MNW | 804523.06 | 397722.13 | 2496.39 | UZUU | No | Yes | 1 | 1Q (4) | 90 | 2Q (2) | 169 | 4Q (1) | 361 | 4Q (1) | 364 |
| 123 | M-74 | MNW | 804056.26 | 397734.78 | 2494.79 | UZUU | No | Yes | 0.5385 | 1Q (4) | 95 | 3Q (1.33) | 234 | 4Q (1) | 361 | 4Q (1) | 364 |
| 124 | M-75 | MNW | 803915.37 | 398152.76 | 2494.615 | UZUU | No | Yes | 0.6154 | 1Q (4) | 98.5 | 15Q (0.27) | 1313 | 4Q (1) | 361 | 4Q (1) | 364 |
| 125 | M-76C | MNW | 803107.09 | 402202.69 | 2467.67 | UZUU | No | Yes | 0.6667 | NA (NA) | NA | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 126 | M-77 | MNW | 801886.47 | 402079.72 | 2400.08 | UZUU | No | Yes | 0.7222 | 2Q (2) | 164.5 | 4Q (1) | 351 | 4Q (1) | 361 | 4Q (1) | 364 |
| 127 | M-78 | MNW | 798659.21 | 399085.78 | 2449.53 | UZUU | No | Yes | 1 | 2Q (2) | 174 | 5Q (0.8) | 428 | 4Q (1) | 361 | 4Q (1) | 364 |
| 128 | M-79 | MNW | 797026.19 | 398026.27 | 2443.34 | LZ-UZLU | No | Yes | 0.8462 | 1Q (4) | 131.5 | NA | NA | 4Q (1) | 364 | 4Q (1) | 364 |
| 129 | M-80 | MNW | 801867.59 | 402622.66 | 2450.905 | LZ-UZLU | No | Yes | 0.5 | 2Q (2) | 169.5 | 4Q (1) | 389 | 4Q (1) | 364 | 4Q (1) | 364 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 130 | M-82 | MNW | 806621.82 | 399247.35 | 2481.59 | UZUU | No | No | 0.3333 | 1Q (4) | 114 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 131 | M-83 | MNW | 806245.19 | 399512.77 | 2479.555 | UZUU | No | No | 0.3333 | 1Q (4) | 118 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 132 | M-84 | MNW | 806486.74 | 399592.67 | 2483.48 | UZUU | No | No | 0.4167 | 1Q (4) | 99.5 | 2Q (2) | 163 | 4Q (1) | 361 | 4Q (1) | 364 |
| 133 | M-85 | MNW | 806553.66 | 399838.42 | 2481.33 | UZUU | No | Yes | 0.5833 | 2Q (2) | 180 | 3Q (1.33) | 285 | 4Q (1) | 361 | 4Q (1) | 364 |
| 134 | M-86 | MNW | 806005.19 | 399614.58 | 2478.25 | UZUU | No | Yes | 0.5 | 1Q (4) | 105 | 2Q (2) | 191 | 4Q (1) | 361 | 4Q (1) | 364 |
| 135 | M-87 | MNW | 806070.22 | 399787.34 | 2480.64 | UZUU | No | Yes | 0.5833 | 1Q (4) | 97.5 | 2Q (2) | 192 | 4Q (1) | 361 | 4Q (1) | 364 |
| 136 | M-88 | MNW | 806115.49 | 399950.7 | 2479.155 | UZUU | No | Yes | 0.5833 | 1Q (4) | 96.5 | 2Q (2) | 206 | 4Q (1) | 361 | 4Q (1) | 364 |
| 137 | M-89 | MNW | 805765.23 | 399686.31 | 2476.685 | UZUU | No | Yes | 0.5 | 1Q (4) | 96 | 2Q (2) | 222 | 4Q (1) | 361 | 4Q (1) | 364 |
| 138 | M-90 | MNW | 806943.72 | 399554.56 | 2483.5 | UZUU | No | Yes | 0.5833 | 2Q (2) | 188 | 3Q (1.33) | 241 | 4Q (1) | 361 | 4Q (1) | 364 |
| 139 | M-91 | MNW | 805928.95 | 400008.9 | 2477.6 | UZUU | No | Yes | 0.5 | 1Q (4) | 99 | 4Q (1) | 405 | 4Q (1) | 361 | 4Q (1) | 364 |
| 140 | M-92 | MNW | 801112.5 | 401999.7 | 2459.465 | UZUU | No | Yes | 0.6 | 1Q (4) | 130.5 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 141 | M-93 | MNW | 801321.8 | 401824 | 2459.65 | UZUU | No | No | 0.3077 | 1Q (4) | 104 | 3Q (1.33) | 303 | 4Q (1) | 361 | 4Q (1) | 364 |
| 142 | M-94 | MNW | 801470.5 | 401936.9 | 2459.625 | UZUU | No | No | 0.4286 | 1Q (4) | 91 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 143 | M-95 | MNW | 801593.5 | 401978.5 | 2460.865 | UZUU | No | No | 0.4 | 2Q (2) | 161 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 144 | M-96 | MNW | 801306.5 | 402104.5 | 2459.22 | UZUU | No | No | 0.0909 | 1Q (4) | 132 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 145 | M-97 | MNW | 801152.5 | 402221.1 | 2459.53 | UZUU | No | No | 0.4545 | 1Q (4) | 94 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 146 | M-98 | MNW | 800899 | 402277.9 | 2462.78 | UZUU | No | No | 0.1667 | 1Q (4) | 90.5 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 147 | M-99 | MNW | 802755 | 402340.41 | 2386.15 | UZUU | No | No | 0.3333 | 1Q (4) | 90.5 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 148 | P-02 | MNW | 798696.91 | 403195.46 | 2482.26 | SGZ | No | Yes | 1 | 2Q (2) | 182.5 | 2Q (2) | 169 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 149 | P-03 | MNW | 797776.32 | 402731.61 | 2472.67 | SGZ | No | Yes | 0.5556 | 2Q (2) | 184 | 4Q (1) | 368 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 150 | P-04 | MNW | 796841.42 | 403154.25 | 2470.265 | SGZ | No | Yes | 0.5714 | 2Q (2) | 212 | 4Q (1) | 339 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 151 | P-05 | MNW | 796793.61 | 401483.96 | 2473.43 | SGZ | Yes | Yes | 1 | 2Q (2) | 183 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 152 | P-06 | MNW | 796861.63 | 403178.14 | 2468.99 | SGZ | No | Yes | 0.6154 | 2Q (2) | 184 | 4Q (1) | 368 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 153 | P-08 | MNW | 799475.74 | 401112.48 | 2495.39 | SGZ | No | No | 0.3333 | 1Q (4) | 58 | 2Q (2) | 143 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 155 | R-07M | OBS | 798233.58 | 405965.41 | 2417.18 | LZ-UZLU | No | Yes | 0.6667 | NA (NA) | NA | NA | NA | 4Q (1) | 364 | 4Q (1) | 364 |
| 156 | R-08M | OBS | 793914.89 | 405484.09 | 2456.48 | LZ-UZLU | No | Yes | 0.8889 | 4Q (1) | 365.5 | NA | NA | 4Q (1) | 364 | 4Q (1) | 364 |
| 157 | R-09M | OBS | 793975.88 | 403940.89 | 2446.55 | LZ-UZLU | No | Yes | 0.7778 | 4Q (1) | 365.5 | NA | NA | 4Q (1) | 364 | 4Q (1) | 364 |
| 158 | R-10M | OBS | 796298.89 | 402248.3 | 2431.63 | UZUU | No | Yes | 0.7273 | 2Q (2) | 186 | 11Q (0.36) | 992 | 4Q (1) | 361 | 4Q (1) | 364 |
| 159 | R-12M | OBS | 798985.19 | 401118.42 | 2445.04 | UZUU | No | No | 0.375 | 1Q (4) | 98 | 2Q (2) | 171 | 4Q (1) | 361 | 4Q (1) | 364 |
| 160 | R-13M | OBS | 800464.82 | 401328.26 | 2403.85 | LZ-UZLU | No | Yes | 0.9231 | 2Q (2) | 142 | 6Q (0.67) | 568 | 4Q (1) | 364 | 4Q (1) | 364 |
| 162 | R-14AM | OBS | 804212.03 | 401097.26 | 2497.73 | UZUU | No | Yes | 0.75 | 2Q (2) | 139.5 | 10Q (0.4) | 884 | 4Q (1) | 361 | 4Q (1) | 364 |
| 163 | S-10 | MNW | 798889.94 | 401153.24 | 2485.32 | SGZ | No | No | 0.1538 | 2Q (2) | 190 | 4Q (1) | 380 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 164 | S-21 | MNW | 799848.47 | 400926.1 | 2516.235 | SGZ | No | Yes | 1 | 1Q (4) | 101 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 165 | S-23 | MNW | 798012.6 | 402369.62 | 2502.535 | SGZ | No | No | 0.2 | 6Q (0.6667) | 554 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 166 | S-24 | EXW | 796843.37 | 403109.4 | 2485.285 | SGZ | No | Yes | 0.5 | 2Q (2) | 185.5 | 1Q (4) | 56 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 167 | S-25 | EXW | 797138.26 | 402930.77 | 2498.7 | SGZ | No | Yes | 0.6667 | 1Q (4) | 93 | 1Q (4) | 110 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 169 | S-27 | EXW | 798183.66 | 402280.65 | 2493.38 | SGZ | No | No | 0.2 | 16Q (0.25) | 1417.5 | 3Q (1.33) | 229 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 170 | S-28 | EXW | 796880.39 | 402529.39 | 2477.14 | SGZ | No | Yes | 0.5 | 2Q (2) | 185.5 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 171 | S-29 | EXW | 797231.17 | 402264.65 | 2488.95 | SGZ | No | Yes | 0.7143 | 2Q (2) | 185 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 172 | S-30 | EXW | 797728.33 | 402085.57 | 2491.51 | SGZ | No | Yes | 0.7692 | 2Q (2) | 184 | 5Q (0.8) | 421 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 173 | S-31 | EXW | 798106.75 | 401867.56 | 2496.16 | SGZ | No | No | 0.3077 | 2Q (2) | 184 | 5Q (0.8) | 453 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 174 | S-32 | MNW | 796310.54 | 403029.62 | 2472.26 | SGZ | No | Yes | 0.6923 | 2Q (2) | 183.5 | 7Q (0.57) | 612 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 175 | S-33 | MNW | 796926.61 | 403610.68 | 2483.07 | SGZ | No | Yes | 1 | 2Q (2) | 184 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 176 | SF-05 | MNW | 796422.33 | 408286.04 | 2382.18 | LZ-UZLU | No | Yes | 0.6154 | 1Q (4) | 107.5 | 3Q (1.33) | 313 | 4Q (1) | 364 | 4Q (1) | 364 |
| 177 | SM-01B | MNW | 798666.55 | 401121.31 | 2471.245 | UZUU | No | Yes | 0.5 | 10Q (0.4) | 913 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 178 | SM-02B | MNW | 798627.53 | 401120.78 | 2473.985 | UZUU | No | Yes | 0.875 | 4Q (1) | 364.5 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 179 | SM-03B | MNW | 798597.2 | 401120.51 | 2473.16 | UZUU | No | Yes | 0.6667 | 4Q (1) | 361 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 180 | SM-04B | MNW | 797558.88 | 402664.2 | 2474.245 | UZUU | No | Yes | 0.5 | 3Q (1.3333) | 268.5 | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 181 | SM-05B | MNW | 796907.25 | 402531.54 | 2481.22 | UZUU | No | Yes | 1 | NA (NA) | NA | NA | NA | 4Q (1) | 361 | 4Q (1) | 364 |
| 182 | SR-01 | EXW | 799016.26 | 401571.71 | 2490.935 | SGZ | No | No | 0.375 | 2Q (2) | 182 | 4Q (1) | 402 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 183 | SR-02 | EXW | 799215.34 | 401703.41 | 2493.82 | SGZ | No | Yes | 0.6 | 2Q (2) | 181.5 | 8Q (0.5) | 679 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 184 | SR-03 | EXW | 799016.24 | 401975.85 | 2492.755 | SGZ | No | No | 0.3333 | 2Q (2) | 209 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 185 | SR-04 | EXW | 798676.97 | 401576.52 | 2491.83 | SGZ | No | No | 0 | 2Q (2) | 186.5 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 186 | SR-05 | EXW | 798616.14 | 401975.03 | 2496.195 | SGZ | No | No | 0 | 2Q (2) | 185 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 187 | SR-07 | EXW | 796789.97 | 403112.9 | 2490.255 | SGZ | No | Yes | 0.625 | 2Q (2) | 182 | 5Q (0.8) | 467 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 188 | SR-08 | EXW | 796803.85 | 402761.87 | 2490.08 | SGZ | No | Yes | 0.75 | 2Q (2) | 185.5 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 189 | SR-09 | EXW | 798969.25 | 402327.03 | 2495.015 | SGZ | No | Yes | 0.75 | 4Q (1) | 371 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 190 | SR-10 | EXW | 799416.69 | 401118.22 | 2494.71 | SGZ | No | No | 0.4 | 2Q (2) | 182 | 5Q (0.8) | 406 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 191 | SR-11 | EXW | 797670.22 | 401671.66 | 2505.98 | SGZ | No | Yes | 1 | NA (NA) | NA | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 192 | SR-12 | EXW | 798078.64 | 402074.64 | 2496.145 | SGZ | No | No | 0.4 | 2Q (2) | 184 | 5Q (0.8) | 491 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 193 | SR-13 | EXW | 799014.24 | 401127.19 | 2493.645 | SGZ | No | No | 0 | 2Q (2) | 185.5 | 5Q (0.8) | 440 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 194 | SR-14 | EXW | 798676.85 | 401121.38 | 2492.49 | SGZ | No | No | 0.3 | 2Q (2) | 189 | 6Q (0.67) | 527 | 5Q (0.8) | 418 | 4Q (1) | 364 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 195 | SR-15 | EXW | 797917.85 | 402374.93 | 2495.295 | SGZ | No | No | 0.3333 | 2Q (2) | 190 | 6Q (0.67) | 507 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 196 | SR-16 | EXW | 797956.36 | 402641.13 | 2497.605 | SGZ | No | Yes | 0.5 | 2Q (2) | 184 | 6Q (0.67) | 532 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 197 | SR-17 | EXW | 797618.21 | 402344.86 | 2493.67 | SGZ | No | No | 0.2 | 2Q (2) | 181.5 | 3Q (1.33) | 298 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 198 | SR-18 | EXW | 798783.43 | 401325.53 | 2493.91 | SGZ | No | No | 0.3333 | 2Q (2) | 197 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 199 | SR-19 | EXW | 799212.29 | 401337.99 | 2495.46 | SGZ | No | No | 0.3 | 2Q (2) | 183 | 4Q (1) | 392 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 200 | SR-20 | EXW | 798851.48 | 400920.02 | 2489.95 | SGZ | No | No | 0.3 | 2Q (2) | 182 | 4Q (1) | 343 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 201 | SR-21 | EXW | 799223.05 | 400938.53 | 2490.735 | SGZ | No | Yes | 0.5 | 2Q (2) | 182 | 4Q (1) | 333 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 202 | SR-22 | EXW | 799815.85 | 401144.46 | 2498.34 | SGZ | No | Yes | 0.875 | 2Q (2) | 189 | 4Q (1) | 379 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 203 | SR-23 | EXW | 798215.35 | 401083.47 | 2491.595 | SGZ | No | Yes | 0.6 | 2Q (2) | 182 | 5Q (0.8) | 447 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 204 | SR-25 | EXW | 799416.09 | 401564.36 | 2495.995 | SGZ | No | No | 0.4 | 2Q (2) | 186 | 9Q (0.44) | 797 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 205 | SR-26 | EXW | 799611.93 | 401349.78 | 2497.235 | SGZ | No | Yes | 0.8 | 2Q (2) | 181.5 | 5Q (0.8) | 431 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 206 | SR-27 | EXW | 799427.93 | 402019.57 | 2498.915 | SGZ | No | Yes | 0.75 | 2Q (2) | 185.5 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 207 | SR-28 | EXW | 796811.81 | 402480.35 | 2496.885 | SGZ | No | Yes | 0.8333 | 2Q (2) | 183 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 208 | SR-29 | EXW | 796803.4 | 402939.93 | 2490.785 | SGZ | No | Yes | 0.75 | 2Q (2) | 185.5 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 209 | SR-30 | EXW | 799606.91 | 400946.99 | 2499.465 | SGZ | No | Yes | 0.7 | 2Q (2) | 182 | 5Q (0.8) | 489 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 210 | SR-31 | EXW | 799019.84 | 400599.01 | 2491.45 | SGZ | No | Yes | 0.5 | 2Q (2) | 182 | 7Q (0.57) | 607 | 5Q (0.8) | 418 | 4Q (1) | 364 |
| 211 | SR-32 | EXW | 799417.19 | 400605.67 | 2498.2 | SGZ | No | Yes | 0.75 | 2Q (2) | 186 | NA | NA | 5Q (0.8) | 418 | 4Q (1) | 364 |

*Sample Elevation*
Approximate elevation at which sample measurements are collected.

*Vertical Zone*
Designated aquifer horizon in which well screen is located.

*Protected Status*
Binary flag designating whether or not well is subject to spatial optimization; 1 = protected from optimization, 0 = eligible for optimization.

*Critical Status*
Binary flag designating whether or not well location is statisticall redundant to current network; 1 = critical, non-redundant, 0 = redundant, non-essential.

*Baseline Frequency (per year)*
Approximate current sampling frequency, rounded to nearest quarter; e.g., 3Q = one sample every 3 quarters; per year = number of samples collected per annum.

*Baseline Interval*
Approximate current sampling interval in days, based on averaging lapsed intervals between distinct sampling events; NA = not enough data to compute.

*Well-Specific Optimal Frequency (per year)*
Approximate optimized sampling frequency, rounded to nearest quarter; e.g., 3Q = one sample every 3 quarters; per year = optimal number of samples collected per annum.

*Well-Specific Optimal Interval*
Approximate optimized sampling interval in days, based on either iterative thinning or temporal variogram range; NA = not enough data to compute.

# GTS New Location Report

## Summary of Suggested New Well Locations

Project = afp44_v2_100309
AFIID/Site = NA
Date Completed = August 5, 2010
Author = MacStat Consulting, Ltd/Kirk Cameron

| Vertical Zone | Easting | Northing | Search Radius | Wells Within Radius | Quantile Score | CV Score |
|---|---|---|---|---|---|---|
| UZUU | 800741.019773 | 407621.218191 | 1292.474412 | 0 | 0.796886 | 1.564576 |
| UZUU | 800741.019773 | 404954.813445 | 1292.474412 | 1 | 0.811564 | 1.418531 |
| SGZ | 798074.615027 | 403177.210282 | 1292.474412 | 18 | 0.752983 | 1.252024 |
| LZ-UZLU | 806962.630846 | 399622.003955 | 1292.474412 | 2 | 0.803566 | 0.45692 |
| LZ-UZLU | 801629.821355 | 398733.202373 | 1292.474412 | 1 | 0.767435 | 0.303518 |
| LZ-UZLU | 798074.615027 | 406732.416609 | 1292.474412 | 3 | 0.872601 | 0.293336 |

*Search Radius*
Radius of uncertainty search.
*Wells Within Radius*
Number of current wells located within search radius distance of proposed location.
*Quantile Score*
Estimated average percentile of site concentrations within search radius distance of proposed location.
*CV Score*
Estimated average coefficient of variation within search radius distance of proposed location.

# Appendix C. NOP Optimization Results

This appendix includes the GTS optimization results at the NOP site computed by the ESTCP project team, as well as the summary report (but not the attachments) submitted by the independent site analyst.

## NOP INDEPENDENT ANALYST SUMMARY REPORT

Report on Beta Testing of GTS Versions from August 2009 through March 2010

Conducted by: Dave Becker, Geologist, U.S. Army Corps of Engineers, Environmental and Munitions Center of Expertise

Preface: I applied GTS to a large dataset from the former Nebraska Ordnance Plant, Mead, Nebraska. The monitoring network included approximately 250 wells in three different depth zones with some monitoring data going back to 1992. This site was also used as a demonstration site for the Summit Envirosolutions long-term monitoring optimization software package under a separately funded ESTCP project. Overall, I found GTS to be a user-friendly and powerful tool. For large sites, in particular, it would be my tool of choice.

1. Usability of the GTS software.

a. *How would you describe and rate general usability, including ease of use*. The software is quite user-friendly. The screens are easy to navigate and read. The screen sequence is logical and appears to be structured to prevent a novice user from by-passing necessary steps. On the other hand, the ability to jump to other steps that have either already been conducted or that can be conducted based on the steps already completed make the program easy to navigate. The graphics included in the program are very nice and clean (though I have some suggestions below). The ability to save and restart is an important capability, and earlier versions had given me some problems in getting back to the point in the sequence where I thought I had saved. Later versions didn't seem to pose that problem.

b. *Installation and set-up issues, including data import and accessibility*. The installation process was somewhat lengthy, but relatively easy. The fact that the software uses a couple of proprietary run-time software means there are several steps to the installation that may be a bit confusing for novice computer users. This should not be an issue for the intended users, though, since they are likely to be quite computer literate. The biggest hurdle for DoD users will likely be that the software will require installation by IT staff with administrator rights. This is a problem for most software, although MAROS can be used without an installation, provided the user has Microsoft Access.

c. *User interface and navigation issues*. The user interface is professional and easy to use, as discussed in paragraph 1a above.

d. *Helpfulness of the User's Guide in navigating and understanding GTS*. The user's guide is well written and concise. There are a number of items and parameters that are not adequately explained, however. In some cases, the ramifications of making certain changes or parameter choices are also not explained. For example, "bandwidth" is not really explained before or at its first use in a way a new user would likely understand (I think my geophysics background helped me). The manual could more fully explain the ramifications of unflagging data points as outliers. Are they or are they not used? It seems they are not used. What happens to the later calculations if you don't change them? What happens if you do? The manual is silent on the genetic algorithm settings for the spatial optimization work. What are the tradeoffs in changing the settings? Other questions for the manual: 1) What are the Logit scores? What are expansion factors?

e. *GTS saving and reporting capabilities*. As described above, there may have been some early problems with the "save" function if an abnormal end to the program occurred, though the save capabilities in later versions did function as intended. There is not a way to save some of the graphics output, other than to do a screen capture, pasting the object into Paint or similar program and then saving as a JPEG file. The ability to save graphics would be very helpful for documenting and reporting the analysis results. Some of the results are presented as tables below the graphics in the separate window that comes up, but these tables can't be fully seen on the screen or printed, such as default bandwidths and selected bandwidths for some items.

f. *GTS graphics capabilities*. The graphics capabilities are very nice but could be improved. First, the maps are fit to a window and the easting and northing scales may not be the same (there is distortion). This affects comparability between some outputs and may not be suitable for reports. For the box plots, different patterns in the boxes, in addition to the different colors, would help those who don't have color printers. One primary suggestion regarding graphics would be to label the wells. I realize this would be a difficult task, but in a complex site with limited site map overlays, this would help identify problems and interpret results. Perhaps the expectation was to have an overlay GIS file with the well ids. A table of actual results below the graph, such as MAROS provides, would be useful. The maps produced by GTS of the contaminant plumes are quite coarse if the default grid is used. Tighter grid spacing could improve the representation, but would extend already long run times.

g. *Encountered bugs, glitches, or other problems*. Given the difficulty in getting IT support for installation of various subsequent builds of GTS, I encountered a number of problems that potentially were related to the version I was using. In some cases it was related to the dataset I was using. I had reported a number of problems to the GTS team and either my mistake was identified or the code was updated. Due to time constraints and early bugs, I was not able to evaluate the Predict module to assess new data. I understand that the software has been used with the Mead dataset through this step by others. One problem I found with the March 2010 version was that I could not go back and reduce the number CoCs once I passed the CoC selection step.

h. *Suggested improvements/refinements*. The program seems to identify too many non-detect values as outliers. The impact of including these as outliers or not is not clear. The process of reviewing and changing outliers is very tedious since you have to enter a well, a contaminant, and a hydraulic zone. When you have 200+ wells, this takes a substantial amount of time. My preference would be to have the program include all data unless the analyst chooses to remove the outlier, rather than the other way around. The same is true of the data gap analysis. If you could show the graphs for all contaminants on one graph and be able to uncheck or check

outliers for each well, it would help. When looking at one contaminant for trends, outliers, etc., if you go to a different well, the contaminant chosen may change if the original contaminant wasn't analyzed for or didn't have an outlier, etc. So you see a graph, but it is not for the contaminant you were expecting. I suggest that if there are no data for the contaminant, show a blank graph, like MAROS does. It would also be good to allow site-specific standards to be input to GTS for inclusion on graphs and in reports.

The run times for the optimization are quite lengthy, particularly for the spatial optimization, which had to run overnight. This is a drawback to the software, but is probably unlikely to be improved much due to the robust and sophisticated nature of the methodology used. It may be useful to allow the optimization to be done one CoC at a time, so the steps could be broken up and the analyst could explore what some of the results might be, rather than waiting until the full analysis is complete.

One major issue I see is that the software did not allow the user to select the optimal plan for the spatial optimization — the software chooses the point on the trade-off curve. It would be interesting for future versions of the software to allow the analyst to explore other points on the trade-off curve.

2. Case study report. I have attached the reports I was able to create and some of the relevant figures generated by GTS for the Mead site data using the March 2010 version of GTS. Due to time constraints, I did not complete the spatial optimization steps with the March 2010 version, but did get the results using the November 2009 version and those results are provided. A completed cost-savings file based on exporting results from GTS analysis and importing them into the cost-savings spreadsheet was not completed due to time constraints; however, I looked through the structure of the file and it appears to be very useful. I realize this is intended to be integrated with GTS, but as a stand-alone spreadsheet, it could conceivably be used to assess the cost changes due to qualitative optimization. I would leave it as a stand-alone program.

As a result of the application of GTS to the Mead data, I was able to assess the spatial and temporal optimization. Based on runs during November 2009, the program was able to recommend a reduction of approximately 20% in the well network and recommended sampling be conducted generally between 9 months (for iterative thinning) to over 1 year (temporal variograms). This is a significant improvement over the current largely semi-annual sampling program. The proportion of wells recommended for removal would have been higher if a large number (over 70) of the site wells were not considered "protected."

## NOP OPTIMIZATION RESULTS

# GTS Optimized Network Status Report

## Summary of Optimized Status for Each Well as Identified by GTS using the NPL Dataset

Project = mead_100128
AFIID/Site = MEAD/MAIN, MEAD/LL1, MEAD/UNKNOWN
Date Completed = August 5, 2010
Author = MacStat Consulting/Kirk Cameron

## Using Iterative Thinning

| GTS Well ID | Loc ID | Well Type | Easting | Northing | Sample Elevation | Vertical Zone | Protected Status | Critical Status | Critical Index | Baseline Frequency (per year) | Baseline Interval (days) | Well-Specific Optimal Frequency (per year) | Well-Specific Optimal Interval (days) | Zone-Based Optimal Frequency (per year) | Zone-Based Optimal Interval (days) | Site-Based Optimal Frequency (per year) | Site-Based Optimal Interval (days) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | MW-01A | MW | 2618460 | 511743 | 1080.4 | MEDIUM | No | Yes | 1 | 2Q (2) | 176 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 6 | MW-01B | MW | 2618470 | 511743 | 1115.2 | SHALLOW | No | Yes | 1 | 2Q (2) | 176 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 7 | MW-02A | MW | 2606800 | 506250 | 1090.3 | MEDIUM | No | Yes | 0.8 | 4Q (1) | 372.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 8 | MW-02B | MW | 2606809 | 506255 | 1123.8 | SHALLOW | No | Yes | 0.7 | 4Q (1) | 372.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 9 | MW-03A | MW | 2607532 | 506223 | 1056.3 | MEDIUM | No | Yes | 0.7 | 4Q (1) | 372 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 10 | MW-03B | MW | 2607542 | 506225 | 1108.45 | SHALLOW | No | Yes | 0.6 | 4Q (1) | 372 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 11 | MW-04A | MW | 2612042 | 506257 | 1077.65 | MEDIUM | No | Yes | 0.75 | 4Q (1) | 363 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 12 | MW-04B | MW | 2612051 | 506259 | 1114.75 | SHALLOW | No | Yes | 0.75 | 6Q (0.6667) | 567 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 13 | MW-05A | MW | 2613044 | 507098 | 1084.8 | MEDIUM | No | Yes | 0.75 | 6Q (0.6667) | 567 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 14 | MW-05B | MW | 2613054 | 507097 | 1121.25 | SHALLOW | No | Yes | 0.9091 | 4Q (1) | 372 | 6Q (0.67) | 541 | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 15 | MW-06A | MW | 2617376 | 506522 | 1082.9 | MEDIUM | No | No | 0.3333 | 2Q (2) | 188 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 16 | MW-06B | MW | 2617385 | 506525 | 1114.2 | SHALLOW | No | Yes | 0.8333 | 2Q (2) | 188 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 17 | MW-07A | MW | 2618267 | 507275 | 1077.85 | MEDIUM | No | Yes | 0.7143 | 4Q (1) | 368 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 18 | MW-07B | MW | 2618277 | 507276 | 1108.1 | SHALLOW | No | Yes | 0.875 | 6Q (0.6667) | 563 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 19 | MW-08A | MW | 2622864 | 506815 | 1060.1 | MEDIUM | No | Yes | 0.7 | 4Q (1) | 366.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 20 | MW-08B | MW | 2622872 | 506821 | 1102.05 | SHALLOW | No | Yes | 0.7273 | 6Q (0.6667) | 558 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 21 | MW-09A | MW | 2623571 | 507436 | 1060.3 | MEDIUM | No | Yes | 0.6667 | 4Q (1) | 365 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 22 | MW-09B | MW | 2623580 | 507436 | 1103.2 | SHALLOW | No | Yes | 0.8333 | 4Q (1) | 365 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 23 | MW-09D | MW | 2623593 | 507436 | 1035.8 | DEEP | No | No | 0.4167 | 4Q (1) | 365 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 24 | MW-100A | MW | 2629719 | 493770 | 1050.6 | MEDIUM | Yes | Yes | 1 | 1Q (4) | 63.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 25 | MW-100B | MW | 2629718 | 493777 | 1068.6 | SHALLOW | Yes | Yes | 1 | 1Q (4) | 63.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 26 | MW-100D | MW | 2629718 | 493784 | 1036.2 | DEEP | Yes | Yes | 1 | 1Q (4) | 63.5 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 27 | MW-101A | MW | 2610929 | 491574 | 1017 | MEDIUM | Yes | Yes | 1 | 1Q (4) | 62 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 28 | MW-101B | MW | 2610924 | 491574 | 1070 | SHALLOW | Yes | Yes | 1 | 1Q (4) | 62 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 29 | MW-101D | MW | 2610935 | 491574 | 1012.5 | DEEP | Yes | Yes | 1 | 1Q (4) | 62 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 30 | MW-102A | MW | 2622929 | 514541 | 1046.8 | MEDIUM | Yes | Yes | 1 | 1Q (4) | 69 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 31 | MW-102B | MW | 2622923 | 514541 | 1113.8 | SHALLOW | Yes | Yes | 1 | 1Q (4) | 69 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 32 | MW-102D | MW | 2622936 | 514541 | 1031.8 | DEEP | Yes | Yes | 1 | 1Q (4) | 69 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 33 | MW-103A | MW | 2623591 | 513116 | 1050.1 | MEDIUM | Yes | Yes | 1 | 1Q (4) | 69 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 34 | MW-103B | MW | 2623591 | 513110 | 1116.4 | SHALLOW | Yes | Yes | 1 | 1Q (4) | 69 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 35 | MW-103D | MW | 2623589 | 513133 | 1038.3 | DEEP | Yes | Yes | 1 | 1Q (4) | 69 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 36 | MW-106A | MW | 2630545 | 506843 | 1053.5 | MEDIUM | Yes | Yes | 1 | 1Q (4) | 72.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 37 | MW-106B | MW | 2630539 | 506844 | 1085.5 | SHALLOW | Yes | Yes | 1 | 1Q (4) | 72.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 38 | MW-106D | MW | 2630549 | 506843 | 1039 | DEEP | Yes | Yes | 1 | 1Q (4) | 72.5 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 39 | MW-107A | MW | 2631376 | 506139 | 1053.1 | MEDIUM | Yes | Yes | 1 | 1Q (4) | 73 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 40 | MW-107B | MW | 2631374 | 506125 | 1087 | SHALLOW | Yes | Yes | 1 | 1Q (4) | 73 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 41 | MW-107D | MW | 2631375 | 506132 | 1038.7 | DEEP | Yes | Yes | 1 | 1Q (4) | 73 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 42 | MW-108A | MW | 2631916 | 505912 | 1051 | MEDIUM | Yes | Yes | 1 | 1Q (4) | 73 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 43 | MW-108B | MW | 2631917 | 505899 | 1087.3 | SHALLOW | Yes | Yes | 1 | 1Q (4) | 73 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 44 | MW-108D | MW | 2631916 | 505906 | 1036.1 | DEEP | Yes | Yes | 1 | 1Q (4) | 73 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 45 | MW-10A | MW | 2607884 | 496858 | 1067 | MEDIUM | Yes | Yes | 1 | 2Q (2) | 195 | 4Q (1) | 367 | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 46 | MW-10B | MW | 2607894 | 496859 | 1100.1 | SHALLOW | Yes | Yes | 1 | 2Q (2) | 195 | 3Q (1.33) | 245 | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 47 | MW-11 | MW | 2626486 | 509500 | 1117.4 | MEDIUM | No | No | 0.4 | 1Q (4) | 100 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 48 | MW-110A | MW | 2634398 | 504433 | 1049.7 | MEDIUM | Yes | Yes | 1 | 1Q (4) | 69.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 49 | MW-110B | MW | 2634397 | 504439 | 1066.5 | SHALLOW | Yes | Yes | 1 | 1Q (4) | 69.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 50 | MW-110D | MW | 2634399 | 504426 | 1039.2 | DEEP | Yes | Yes | 1 | 1Q (4) | 69.5 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 51 | MW-112A | MW | 2637366 | 501826 | 1037.4 | MEDIUM | Yes | Yes | 1 | 1Q (4) | 73 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 52 | MW-112B | MW | 2637365 | 501833 | 1058.9 | SHALLOW | Yes | Yes | 1 | 1Q (4) | 73 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 53 | MW-113A | MW | 2637420 | 500472 | 1042.3 | MEDIUM | Yes | Yes | 1 | 1Q (4) | 73 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 54 | MW-113B | MW | 2637420 | 500478 | 1052.3 | SHALLOW | Yes | Yes | 1 | 1Q (4) | 73 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 55 | MW-113D | MW | 2637420 | 500466 | 1029.6 | DEEP | Yes | Yes | 1 | 1Q (4) | 73 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 56 | MW-114A | MW | 2637471 | 497207 | 1035.9 | MEDIUM | Yes | Yes | 1 | 1Q (4) | 67.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 57 | MW-114B | MW | 2637466 | 497204 | 1052.9 | SHALLOW | Yes | Yes | 1 | 1Q (4) | 67.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 58 | MW-114D | MW | 2637476 | 497210 | 1022.7 | DEEP | Yes | Yes | 1 | 1Q (4) | 67.5 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 59 | MW-115A | MW | 2637703 | 495347 | 1033.9 | MEDIUM | Yes | Yes | 1 | 1Q (4) | 66.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 60 | MW-115B | MW | 2637696 | 495347 | 1048.9 | SHALLOW | Yes | Yes | 1 | 1Q (4) | 66.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 61 | MW-115D | MW | 2637709 | 495347 | 1022.75 | DEEP | Yes | Yes | 1 | 1Q (4) | 66.5 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 62 | MW-116A | MW | 2636336 | 495298 | 1038.1 | MEDIUM | Yes | Yes | 1 | 1Q (4) | 67.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 63 | MW-116B | MW | 2636332 | 495297 | 1048.6 | SHALLOW | Yes | Yes | 1 | 1Q (4) | 67.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 64 | MW-116D | MW | 2636334 | 495294 | 1027.35 | DEEP | Yes | Yes | 1 | 1Q (4) | 67.5 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 65 | MW-117A | MW | 2631041 | 495048 | 1051.4 | MEDIUM | No | Yes | 0.75 | 1Q (4) | 63.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 66 | MW-117B | MW | 2631041 | 495054 | 1074.4 | SHALLOW | No | Yes | 0.5 | 1Q (4) | 63.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 67 | MW-117D | MW | 2631042 | 495042 | 1038.4 | DEEP | No | Yes | 0.5 | 1Q (4) | 63.5 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 68 | MW-118A | MW | 2625890 | 496208 | 1046.35 | MEDIUM | No | Yes | 0.5 | 1Q (4) | 65 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 69 | MW-118B | MW | 2625885 | 496208 | 1065.2 | SHALLOW | No | Yes | 1 | 1Q (4) | 65 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 70 | MW-12 | MW | 2606856 | 509014 | 1143.85 | SHALLOW | No | Yes | 1 | 2Q (2) | 187 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 71 | MW-13 | MW | 2612231 | 509179 | 1138.45 | SHALLOW | No | Yes | 0.75 | 1Q (4) | 95 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 72 | MW-14 | MW | 2617505 | 509391 | 1133.35 | SHALLOW | No | Yes | 0.75 | 2Q (2) | 187 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 73 | MW-15 | MW | 2622745 | 509483 | 1125.85 | SHALLOW | No | Yes | 1 | 2Q (2) | 195 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 74 | MW-16B | MW | 2604912 | 514026 | | MEDIUM | No | Yes | 0.5 | 1Q (4) | 88 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 75 | MW-16C | MW | 2604918 | 514035 | 1150.2 | SHALLOW | No | Yes | 0.8571 | 1Q (4) | 94.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 76 | MW-17A | MW | 2603293 | 499100 | 1051.8 | DEEP | No | No | 0.375 | 2Q (2) | 184.5 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 77 | MW-17B | MW | 2603293 | 499101 | 1073.1 | MEDIUM | No | Yes | 0.625 | 2Q (2) | 184.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 78 | MW-17C | MW | 2603293 | 499090 | 1114 | SHALLOW | No | Yes | 1 | 2Q (2) | 181 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 79 | MW-18A | MW | 2629150 | 506832 | 1019.3 | DEEP | No | Yes | 0.6667 | 2Q (2) | 136.5 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 80 | MW-18B | MW | 2629157 | 506827 | | MEDIUM | No | Yes | 0.7 | 1Q (4) | 100 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 81 | MW-18C | MW | 2629149 | 506822 | 1101.7 | SHALLOW | No | Yes | 0.6667 | 2Q (2) | 136.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 82 | MW-19A | MW | 2618421 | 517577 | 1029.8 | DEEP | No | Yes | 0.5455 | 2Q (2) | 168 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 83 | MW-19B | MW | 2618430 | 517577 | 1055.8 | MEDIUM | No | Yes | 0.6364 | 2Q (2) | 168 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 84 | MW-19C | MW | 2618426 | 517569 | 1141.35 | SHALLOW | No | Yes | 0.9 | 2Q (2) | 138.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 85 | MW-20A | MW | 2616623 | 493190 | 1010.3 | DEEP | Yes | Yes | 1 | 3Q (1.3333) | 240 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 86 | MW-20B | MW | 2616633 | 493191 | 1026.6 | MEDIUM | Yes | Yes | 1 | 4Q (1) | 358 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 87 | MW-20C | MW | 2616611 | 493188 | 1102.5 | SHALLOW | Yes | Yes | 1 | 4Q (1) | 366 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 88 | MW-21A | MW | 2607121 | 503525 | 1042.7 | MEDIUM | No | Yes | 0.7143 | 2Q (2) | 217 | 4Q (1) | 357 | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 89 | MW-21B | MW | 2607111 | 503524 | 1092.7 | SHALLOW | No | Yes | 1 | 2Q (2) | 196.5 | 7Q (0.57) | 649 | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 90 | MW-21D | MW | 2607131 | 503526 | 1028.2 | DEEP | No | Yes | 0.5 | 2Q (2) | 199 | 9Q (0.44) | 803 | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 91 | MW-22A | MW | 2606598 | 510402 | 1082.1 | MEDIUM | No | Yes | 0.75 | 2Q (2) | 175 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 92 | MW-22B | MW | 2606604 | 510403 | 1111.8 | SHALLOW | No | Yes | 0.75 | 2Q (2) | 175 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 93 | MW-23A | MW | 2606403 | 509376 | 1078.4 | MEDIUM | No | No | 0.4444 | 2Q (2) | 173 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 94 | MW-23B | MW | 2606393 | 509384 | 1099.5 | SHALLOW | No | Yes | 1 | 2Q (2) | 190 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 95 | MW-24A | MW | 2608477 | 501920 | 1044.9 | MEDIUM | No | Yes | 0.7857 | 3Q (1.3333) | 270.5 | 7Q (0.57) | 673 | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 96 | MW-24B | MW | 2608478 | 501909 | 1100.3 | DEEP | No | Yes | 0.7143 | 3Q (1.3333) | 271 | 7Q (0.57) | 620 | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 97 | MW-25A | MW | 2608308 | 504875 | 1023.2 | MEDIUM | No | Yes | 0.7 | 4Q (1) | 378.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 98 | MW-25B | MW | 2608308 | 504886 | 1093.9 | SHALLOW | No | Yes | 0.9 | 4Q (1) | 378.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 99 | MW-25D | MW | 2608309 | 504865 | 1007.8 | DEEP | No | Yes | 0.6 | 4Q (1) | 378.5 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 100 | MW-26A | MW | 2609860 | 508825 | 1074.9 | MEDIUM | No | Yes | 0.5 | 1Q (4) | 91 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 101 | MW-26B | MW | 2609850 | 508825 | 1101.4 | SHALLOW | No | Yes | 1 | 1Q (4) | 91 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 102 | MW-27A | MW | 2611435 | 508103 | 1073.1 | MEDIUM | No | Yes | 0.6 | 29Q (0.1379) | 2574.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 103 | MW-27B | MW | 2611427 | 508111 | 1107.6 | SHALLOW | No | Yes | 0.8 | 29Q (0.1379) | 2574.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 104 | MW-28A | MW | 2612951 | 502243 | 1037.7 | MEDIUM | No | Yes | 0.8 | 2Q (2) | 181.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 105 | MW-28B | MW | 2612936 | 502242 | 1097.9 | SHALLOW | No | Yes | 0.8 | 2Q (2) | 182 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 106 | MW-28D | MW | 2612970 | 502243 | 1023.3 | DEEP | No | No | 0.4 | 2Q (2) | 181 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 107 | MW-29A | MW | 2614470 | 498383 | 1030.9 | MEDIUM | No | Yes | 0.5455 | 2Q (2) | 193 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 108 | MW-29B | MW | 2614461 | 498382 | 1089.3 | SHALLOW | No | Yes | 0.8333 | 4Q (1) | 361.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 109 | MW-30A | MW | 2616288 | 507065 | 1070.1 | MEDIUM | No | Yes | 0.5 | 6Q (0.6667) | 540 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 110 | MW-30B | MW | 2616282 | 507066 | 1101.9 | SHALLOW | No | Yes | 0.8333 | 6Q (0.6667) | 540 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 111 | MW-31A | MW | 2617944 | 503234 | 1065.8 | MEDIUM | No | Yes | 0.8889 | 3Q (1.3333) | 279 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 112 | MW-31B | MW | 2617935 | 503239 | 1110.1 | SHALLOW | No | Yes | 0.6667 | 3Q (1.3333) | 279 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 113 | MW-32A | MW | 2619697 | 499062 | 1058.8 | MEDIUM | No | Yes | 0.7273 | 4Q (1) | 355 | 7Q (0.57) | 668 | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 114 | MW-32B | MW | 2619697 | 499069 | 1076.3 | SHALLOW | No | Yes | 0.8182 | 4Q (1) | 355 | 11Q (0.36) | 1033 | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 115 | MW-32D | MW | 2619698 | 499056 | 1043.1 | DEEP | No | No | 0.4545 | 4Q (1) | 355 | 7Q (0.57) | 631 | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 116 | MW-33A | MW | 2622411 | 502848 | 1052.9 | MEDIUM | No | Yes | 0.9091 | 5Q (0.8) | 455 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 117 | MW-33B | MW | 2622401 | 502855 | 1080 | SHALLOW | No | Yes | 0.8182 | 5Q (0.8) | 455 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 118 | MW-33D | MW | 2622422 | 502857 | 1035.8 | DEEP | No | Yes | 0.8182 | 4Q (1) | 373 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 119 | MW-34A | MW | 2624443 | 498806 | 1048.1 | MEDIUM | No | Yes | 0.7273 | 2Q (2) | 191.5 | 3Q (1.33) | 306 | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 120 | MW-34B | MW | 2624443 | 498814 | 1085 | SHALLOW | No | No | 0.4545 | 2Q (2) | 191.5 | 4Q (1) | 340 | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 121 | MW-34D | MW | 2624442 | 498796 | 1032.3 | DEEP | No | Yes | 0.7273 | 4Q (1) | 355 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 122 | MW-35A | MW | 2629596 | 496324 | 1051.3 | MEDIUM | No | Yes | 0.75 | 2Q (2) | 177.5 | 4Q (1) | 317 | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 123 | MW-35B | MW | 2629596 | 496329 | 1075.8 | SHALLOW | No | Yes | 0.9167 | 2Q (2) | 177.5 | 3Q (1.33) | 262 | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 124 | MW-35D | MW | 2629596 | 496317 | 1034.8 | DEEP | No | No | 0.3333 | 2Q (2) | 180 | 5Q (0.8) | 449 | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 125 | MW-36A | MW | 2634815 | 496695 | 1043.8 | MEDIUM | No | Yes | 0.9286 | 2Q (2) | 181 | 7Q (0.57) | 656 | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 126 | MW-36B | MW | 2634806 | 496693 | 1054.8 | SHALLOW | No | Yes | 0.6429 | 2Q (2) | 181 | 4Q (1) | 394 | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 127 | MW-36D | MW | 2634824 | 496698 | 1031.4 | DEEP | No | Yes | 0.7857 | 2Q (2) | 184 | 13Q (0.31) | 1200 | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 128 | MW-37A | MW | 2633418 | 491652 | 1047.6 | MEDIUM | No | Yes | 0.7857 | 2Q (2) | 181 | 3Q (1.33) | 227 | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 129 | MW-37B | MW | 2633417 | 491632 | 1056.6 | SHALLOW | No | Yes | 0.7143 | 2Q (2) | 181 | 3Q (1.33) | 236 | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 130 | MW-37D | MW | 2633414 | 491666 | 1035 | DEEP | No | No | 0.4286 | 2Q (2) | 181 | 3Q (1.33) | 236 | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 131 | MW-38A | MW | 2638132 | 496249 | 1033.05 | MEDIUM | No | Yes | 0.75 | 2Q (2) | 203.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 132 | MW-38D | MW | 2638139 | 496251 | 1019 | DEEP | No | No | 0.25 | 2Q (2) | 201 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 133 | MW-39A | MW | 2640060 | 499307 | 1034.75 | MEDIUM | No | Yes | 0.6 | 4Q (1) | 374.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 134 | MW-39D | MW | 2640059 | 499299 | 1027.1 | DEEP | No | No | 0.1 | 4Q (1) | 374.5 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 135 | MW-40A | MW | 2623019 | 511963 | 1047.1 | MEDIUM | No | Yes | 0.7143 | 4Q (1) | 365.5 | 12Q (0.33) | 1063 | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 136 | MW-40B | MW | 2623007 | 511963 | 1111.4 | SHALLOW | No | Yes | 0.7778 | 4Q (1) | 382.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 137 | MW-41A | MW | 2624371 | 512001 | 1089.8 | MEDIUM | Yes | Yes | 1 | 2Q (2) | 202 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 138 | MW-41B | MW | 2624362 | 512001 | 1125.3 | SHALLOW | Yes | Yes | 1 | 2Q (2) | 202 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 139 | MW-41D | MW | 2624353 | 512001 | 1076.9 | DEEP | Yes | Yes | 1 | 2Q (2) | 202 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 140 | MW-42A | MW | 2629385 | 501583 | 1053.5 | MEDIUM | No | Yes | 0.7857 | 2Q (2) | 207 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 141 | MW-42B | MW | 2629385 | 501593 | 1086.5 | SHALLOW | No | Yes | 0.8571 | 2Q (2) | 207 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 142 | MW-42D | MW | 2629385 | 501572 | 1038.7 | DEEP | No | Yes | 0.6667 | 2Q (2) | 177 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 143 | MW-43A | MW | 2629243 | 504318 | 1045.5 | MEDIUM | No | Yes | 0.9167 | 3Q (1.3333) | 282.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 144 | MW-43B | MW | 2629244 | 504328 | 1095.9 | SHALLOW | No | Yes | 0.9167 | 3Q (1.3333) | 282.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 145 | MW-43D | MW | 2629242 | 504308 | 1032.1 | DEEP | No | No | 0.4167 | 2Q (2) | 205 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 146 | MW-44A | MW | 2632954 | 500415 | 1057.4 | MEDIUM | No | Yes | 0.7857 | 2Q (2) | 182 | 3Q (1.33) | 313 | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 147 | MW-44B | MW | 2632955 | 500426 | 1069.6 | SHALLOW | No | Yes | 0.8571 | 2Q (2) | 183.5 | 3Q (1.33) | 279 | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 148 | MW-44D | MW | 2632953 | 500404 | 1039 | DEEP | No | Yes | 0.5714 | 2Q (2) | 183.5 | 4Q (1) | 344 | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 149 | MW-45A | MW | 2635044 | 499241 | 1046.6 | MEDIUM | No | Yes | 0.8333 | 2Q (2) | 179 | 5Q (0.8) | 414 | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 150 | MW-45B | MW | 2635054 | 499241 | 1057.5 | SHALLOW | No | Yes | 0.6667 | 2Q (2) | 179 | 6Q (0.67) | 524 | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 151 | MW-45D | MW | 2635032 | 499242 | 1034.2 | DEEP | No | No | 0.4167 | 2Q (2) | 179 | 6Q (0.67) | 524 | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 152 | MW-46A | MW | 2637465 | 499387 | 1042.5 | MEDIUM | Yes | Yes | 1 | 2Q (2) | 185 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 153 | MW-46B | MW | 2637464 | 499397 | 1054.8 | SHALLOW | Yes | Yes | 1 | 2Q (2) | 208 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 154 | MW-46D | MW | 2637465 | 499376 | 1025.7 | DEEP | Yes | Yes | 1 | 2Q (2) | 185 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 155 | MW-47A | MW | 2603835 | 524481 | 1082 | MEDIUM | No | Yes | 0.7 | 1Q (4) | 134.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 156 | MW-47B | MW | 2603819 | 524480 | 1120 | SHALLOW | No | Yes | 1 | 1Q (4) | 134.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 157 | MW-48A | MW | 2607437 | 519363 | 1075.7 | MEDIUM | No | Yes | 0.6667 | 4Q (1) | 372.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 158 | MW-48B | MW | 2607443 | 519368 | 1113.3 | SHALLOW | No | Yes | 0.8889 | 4Q (1) | 372.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 159 | MW-48D | MW | 2607428 | 519358 | 1063.6 | DEEP | No | Yes | 0.7778 | 4Q (1) | 372.5 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 160 | MW-52A | MW | 2627013 | 508785 | 1100.5 | MEDIUM | No | Yes | 0.7 | 1Q (4) | 97.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 161 | MW-52B | MW | 2627004 | 508779 | 1106.4 | SHALLOW | No | Yes | 0.9 | 1Q (4) | 97.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 162 | MW-53A | MW | 2627898 | 508170 | 1042.4 | MEDIUM | No | Yes | 0.5 | 1Q (4) | 96.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 163 | MW-53B | MW | 2627885 | 508167 | 1102.4 | SHALLOW | No | Yes | 0.5 | 3Q (1.3333) | 263.5 | 5Q (0.8) | 422 | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 164 | MW-54A | MW | 2627894 | 508858 | 1048.7 | MEDIUM | No | Yes | 0.6667 | 2Q (2) | 139.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 165 | MW-54B | MW | 2627884 | 508856 | 1093.2 | SHALLOW | No | Yes | 0.75 | 2Q (2) | 139.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 166 | MW-55A | MW | 2628135 | 508378 | 1045.5 | MEDIUM | No | Yes | 0.5833 | 1Q (4) | 110 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 167 | MW-55B | MW | 2628126 | 508374 | 1064.1 | SHALLOW | No | Yes | 0.5833 | 1Q (4) | 110 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 168 | MW-56A | MW | 2628206 | 508215 | 1050.2 | MEDIUM | No | Yes | 0.5 | 1Q (4) | 97.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 169 | MW-56B | MW | 2628195 | 508217 | 1098.4 | SHALLOW | No | No | 0.3 | 1Q (4) | 97 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 170 | MW-57B | MW | 2607622 | 516363 | 1134.3 | SHALLOW | No | Yes | 1 | 2Q (2) | 182 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 171 | MW-58A | MW | 2620357 | 515008 | 1046 | MEDIUM | No | Yes | 0.6667 | 4Q (1) | 375 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 172 | MW-58B | MW | 2620346 | 515010 | 1097.7 | SHALLOW | No | Yes | 0.7778 | 4Q (1) | 375 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 173 | MW-59A | MW | 2621708 | 515882 | 1043 | MEDIUM | No | Yes | 0.5556 | 4Q (1) | 367.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 174 | MW-59B | MW | 2621701 | 515888 | 1118.3 | SHALLOW | No | Yes | 0.6667 | 4Q (1) | 367.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 175 | MW-59D | MW | 2621717 | 515878 | 1026.1 | DEEP | No | No | 0.1111 | 4Q (1) | 367.5 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 176 | MW-60A | MW | 2624703 | 489585 | 1046.9 | MEDIUM | No | Yes | 0.6667 | 3Q (1.3333) | 236.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 177 | MW-60B | MW | 2624703 | 489599 | 1069.1 | SHALLOW | No | Yes | 0.5 | 3Q (1.3333) | 236.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 178 | MW-61A | MW | 2608656 | 492900 | 1026.2 | MEDIUM | No | Yes | 0.5556 | 2Q (2) | 189 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 179 | MW-61B | MW | 2608644 | 492899 | 1076.8 | SHALLOW | No | Yes | 0.5556 | 2Q (2) | 194.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 180 | MW-61D | MW | 2608668 | 492902 | 1007.3 | DEEP | No | No | 0.3333 | 2Q (2) | 189 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 181 | MW-62A | MW | 2635397 | 493874 | 1044.6 | MEDIUM | Yes | Yes | 1 | 2Q (2) | 183 | 7Q (0.57) | 644 | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 182 | MW-62B | MW | 2635385 | 493872 | 1056 | SHALLOW | Yes | Yes | 1 | 2Q (2) | 183 | 3Q (1.33) | 286 | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 183 | MW-62D | MW | 2635407 | 493877 | 1030.4 | DEEP | Yes | Yes | 1 | 2Q (2) | 183 | 4Q (1) | 389 | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 184 | MW-64B | MW | 2628039 | 510106 | 1118.3 | SHALLOW | No | Yes | 0.5 | 24Q (0.1667) | 2149.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 185 | MW-65A | MW | 2613203 | 506091 | 1067.3 | MEDIUM | No | Yes | 0.6667 | 4Q (1) | 372 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 186 | MW-65B | MW | 2613193 | 506091 | 1114.5 | SHALLOW | No | Yes | 0.6667 | 4Q (1) | 372 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 187 | MW-66A | MW | 2613279 | 506027 | 1069.9 | MEDIUM | No | Yes | 0.6667 | 4Q (1) | 372 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 188 | MW-67A | MW | 2613306 | 506004 | 1070.3 | MEDIUM | No | No | 0.3333 | 4Q (1) | 372 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 189 | MW-67B | MW | 2613315 | 505999 | 1114.5 | SHALLOW | No | Yes | 0.6667 | 4Q (1) | 372 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 190 | MW-72A | MW | 2622931 | 512065 | 1073.2 | MEDIUM | No | Yes | 1 | 4Q (1) | 372 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 191 | MW-72B | MW | 2622922 | 512064 | 1115.8 | SHALLOW | No | Yes | 0.6667 | 4Q (1) | 361 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 192 | MW-73A | MW | 2623061 | 511909 | 1069.8 | MEDIUM | No | Yes | 0.6667 | 4Q (1) | 373 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 193 | MW-73B | MW | 2623052 | 511909 | 1112.7 | SHALLOW | No | Yes | 0.6667 | 4Q (1) | 361.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 194 | MW-79A | MW | 2610432 | 492336 | 1026.2 | MEDIUM | No | No | 0.4 | 1Q (4) | 84 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 195 | MW-79B | MW | 2610428 | 492345 | 1072 | SHALLOW | No | Yes | 0.8 | 1Q (4) | 84 | 1Q (4) | 112 | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 196 | MW-80A | MW | 2610926 | 492067 | 1031.1 | MEDIUM | No | No | 0.4 | 1Q (4) | 85 | 1Q (4) | 105 | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 197 | MW-80B | MW | 2610916 | 492065 | 1070.5 | SHALLOW | No | No | 0.4 | 1Q (4) | 85 | 2Q (2) | 151 | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 198 | MW-80D | MW | 2610936 | 492069 | 1015 | DEEP | No | No | 0.4 | 1Q (4) | 85 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 199 | MW-81A | MW | 2611638 | 492369 | 1020.8 | MEDIUM | No | No | 0 | 1Q (4) | 85 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 200 | MW-81B | MW | 2611636 | 492360 | 1073.1 | SHALLOW | No | Yes | 0.6 | 1Q (4) | 85 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 201 | MW-81D | MW | 2611633 | 492350 | 1004.8 | DEEP | No | Yes | 0.6 | 1Q (4) | 85 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 202 | MW-82A | MW | 2619289 | 493318 | 1055.1 | MEDIUM | Yes | Yes | 1 | 2Q (2) | 137.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 203 | MW-82B | MW | 2619285 | 493325 | 1083.75 | SHALLOW | Yes | Yes | 1 | 2Q (2) | 137.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 204 | MW-82D | MW | 2619293 | 493311 | 1024.6 | DEEP | Yes | Yes | 1 | 2Q (2) | 137 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 205 | MW-83A | MW | 2621924 | 495275 | 1044.2 | MEDIUM | No | Yes | 0.6667 | 2Q (2) | 137 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 206 | MW-83B | MW | 2621922 | 495303 | 1072.9 | SHALLOW | No | Yes | 0.6667 | 2Q (2) | 137 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 207 | MW-83D | MW | 2621923 | 495289 | 1031.8 | DEEP | No | Yes | 0.5 | 2Q (2) | 137 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 208 | MW-84A | MW | 2624278 | 495686 | 1054.1 | MEDIUM | No | Yes | 0.8333 | 2Q (2) | 137.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 209 | MW-84AR | MW | 2624274 | 495704 | 1043.2 | MEDIUM | No | No | 0 | NA (NA) | NA | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 210 | MW-84B | MW | 2624272 | 495713 | 1074.3 | SHALLOW | No | Yes | 0.6667 | 2Q (2) | 137.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 211 | MW-84D | MW | 2624276 | 495696 | 1037.2 | DEEP | No | Yes | 0.6667 | 2Q (2) | 137.5 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 212 | MW-85A | MW | 2628327 | 494439 | 1047 | MEDIUM | No | Yes | 0.8333 | 2Q (2) | 136.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 213 | MW-85B | MW | 2628315 | 494450 | 1065.9 | SHALLOW | No | Yes | 0.6667 | 2Q (2) | 136.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 214 | MW-85D | MW | 2628339 | 494428 | 1037.9 | DEEP | No | Yes | 0.6667 | 2Q (2) | 136.5 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 215 | MW-86A | MW | 2631939 | 493760 | 1054.3 | MEDIUM | No | Yes | 0.5 | 1Q (4) | 68.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 216 | MW-86B | MW | 2631934 | 493759 | 1064.1 | SHALLOW | No | Yes | 0.75 | 1Q (4) | 68.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 217 | MW-86D | MW | 2631944 | 493760 | 1039.75 | DEEP | No | No | 0 | 1Q (4) | 68.5 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 218 | MW-87A | MW | 2635040 | 491898 | 1034.8 | MEDIUM | Yes | Yes | 1 | 1Q (4) | 70 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 219 | MW-87B | MW | 2635035 | 491901 | 1053.8 | SHALLOW | Yes | Yes | 1 | 1Q (4) | 70 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 220 | MW-87D | MW | 2635044 | 491895 | 1022.95 | DEEP | Yes | Yes | 1 | 1Q (4) | 70 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 221 | MW-88A | MW | 2637644 | 494045 | 1038.7 | MEDIUM | Yes | Yes | 1 | 1Q (4) | 68.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 222 | MW-88B | MW | 2637639 | 494044 | 1053.7 | SHALLOW | Yes | Yes | 1 | 1Q (4) | 68.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 223 | MW-88D | MW | 2637649 | 494046 | 1025.7 | DEEP | Yes | Yes | 1 | 1Q (4) | 68.5 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 224 | MW-89A | MW | 2610431 | 494254 | 1024.6 | MEDIUM | No | Yes | 0.5 | 1Q (4) | 80 | 2Q (2) | 204 | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 225 | MW-89B | MW | 2610409 | 494254 | 1088.85 | SHALLOW | No | Yes | 0.5 | 1Q (4) | 83 | 2Q (2) | 156 | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 226 | MW-89D | MW | 2610451 | 494254 | 1010.8 | DEEP | No | Yes | 0.5 | 1Q (4) | 83 | 2Q (2) | 223 | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 227 | MW-90A | MW | 2611236 | 494302 | 1031.1 | MEDIUM | No | Yes | 0.6667 | 1Q (4) | 83 | 2Q (2) | 177 | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 228 | MW-90B | MW | 2611227 | 494298 | 1078.15 | SHALLOW | No | Yes | 0.8333 | 1Q (4) | 85 | 1Q (4) | 124 | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 229 | MW-90D | MW | 2611245 | 494306 | 1016.6 | DEEP | No | Yes | 0.5 | 1Q (4) | 85 | 2Q (2) | 136 | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 230 | MW-91A | MW | 2612077 | 494323 | 1035.7 | MEDIUM | No | Yes | 0.6667 | 1Q (4) | 80.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 231 | MW-91B | MW | 2612068 | 494318 | 1077.1 | SHALLOW | No | Yes | 1 | 1Q (4) | 85 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 232 | MW-91D | MW | 2612086 | 494328 | 1022.1 | DEEP | No | Yes | 0.8333 | 1Q (4) | 85 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 233 | MW-92A | MW | 2610047 | 492723 | 1029.4 | MEDIUM | No | Yes | 0.8333 | 1Q (4) | 85 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 234 | MW-92B | MW | 2610048 | 492734 | 1071.3 | SHALLOW | No | Yes | 0.8333 | 1Q (4) | 85 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 235 | MW-93A | MW | 2612163 | 493551 | 1032.9 | MEDIUM | No | Yes | 1 | 1Q (4) | 84 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 236 | MW-93B | MW | 2612154 | 493547 | 1056.7 | SHALLOW | No | Yes | 0.8333 | 1Q (4) | 84 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 240 | MW-94A | MW | 2617023 | 496429 | 1061.8 | MEDIUM | No | No | 0 | 1Q (4) | 66 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 241 | MW-94B | MW | 2617023 | 496434 | 1081.6 | SHALLOW | No | Yes | 0.5 | 1Q (4) | 66 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 242 | MW-94D | MW | 2617023 | 496423 | 1032.15 | DEEP | No | No | 0 | 1Q (4) | 66 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 243 | MW-95A | MW | 2617553 | 494509 | 1056.3 | MEDIUM | Yes | Yes | 1 | 1Q (4) | 64.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 244 | MW-95B | MW | 2617547 | 494508 | 1084.2 | SHALLOW | Yes | Yes | 1 | 1Q (4) | 64.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 245 | MW-95D | MW | 2617558 | 494509 | 1027.5 | DEEP | Yes | Yes | 1 | 1Q (4) | 64.5 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 246 | MW-96A | MW | 2621468 | 493388 | 1058.5 | MEDIUM | Yes | Yes | 1 | 1Q (4) | 69.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 247 | MW-96B | MW | 2621468 | 493388 | 1070 | SHALLOW | Yes | Yes | 1 | 1Q (4) | 69.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 248 | MW-96D | MW | 2621476 | 493388 | 1042.25 | DEEP | Yes | Yes | 1 | 1Q (4) | 69.5 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 249 | MW-97A | MW | 2623938 | 493493 | 1052.6 | MEDIUM | Yes | Yes | 1 | 1Q (4) | 66.5 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 250 | MW-97B | MW | 2623933 | 493492 | 1070.1 | SHALLOW | Yes | Yes | 1 | 1Q (4) | 66.5 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| | MW | | | | | | | | | | | | | | | | |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 251 | MW-97D | MW | 2623943 | 493493 | 1037.85 | DEEP | Yes | Yes | 1 | 1Q (4) | 66.5 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 252 | MW-98A | MW | 2626495 | 493605 | 1052 | MEDIUM | Yes | Yes | 1 | 1Q (4) | 62 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 253 | MW-98B | MW | 2626489 | 493605 | 1072.5 | SHALLOW | Yes | Yes | 1 | 1Q (4) | 62 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 254 | MW-98D | MW | 2626502 | 493605 | 1039.5 | DEEP | Yes | Yes | 1 | 1Q (4) | 62 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |
| 255 | MW-99A | MW | 2627117 | 498781 | 1053.7 | MEDIUM | No | Yes | 0.5 | 1Q (4) | 62 | NA | NA | 4Q (1) | 353 | 4Q (1) | 328.5 |
| 256 | MW-99B | MW | 2627118 | 498788 | 1080.9 | SHALLOW | No | Yes | 1 | 1Q (4) | 62 | NA | NA | 3Q (1.33) | 299 | 4Q (1) | 328.5 |
| 257 | MW-99D | MW | 2627117 | 498774 | 1039.4 | DEEP | No | No | 0 | 1Q (4) | 62 | NA | NA | 4Q (1) | 389.5 | 4Q (1) | 328.5 |

*Sample Elevation*
Approximate elevation at which sample measurements are collected.
*Vertical Zone*
Designated aquifer horizon in which well screen is located.
*Protected Status*
Binary flag designating whether or not well is subject to spatial optimization; 1 = protected from optimization, 0 = eligible for optimization.
*Critical Status*
Binary flag designating whether or not well location is statisticall redundant to current network; 1 = critical, non-redundant, 0 = redundant, non-essential.
*Baseline Frequency (per year)*
Approximate current sampling frequency, rounded to nearest quarter; e.g., 3Q = one sample every 3 quarters; per year = number of samples collected per annum.
*Baseline Interval*
Approximate current sampling interval in days, based on averaging lapsed intervals between distinct sampling events; NA = not enough data to compute.
*Well-Specific Optimal Frequency (per year)*
Approximate optimized sampling frequency, rounded to nearest quarter; e.g., 3Q = one sample every 3 quarters; per year = optimal number of samples collected per annum.
*Well-Specific Optimal Interval*
Approximate optimized sampling interval in days, based on either iterative thinning or temporal variogram range; NA = not enough data to compute.

# GTS New Location Report

## Summary of Suggested New Well Locations

Project = mead_100128
AFIID/Site = MEAD/MAIN, MEAD/LL1, MEAD/UNKNOWN
Date Completed = August 5, 2010
Author = MacStat Consulting/Kirk Cameron

| Vertical Zone | Easting | Northing | Search Radius | Wells Within Radius | Quantile Score | CV Score |
|---|---|---|---|---|---|---|
| SHALLOW | 2615000.315641 | 515001.114522 | 3238.806818 | 0 | 0.888613 | 2.50646 |
| SHALLOW | 2615000.315641 | 519523.047482 | 3238.806818 | 0 | 0.864666 | 2.496197 |
| SHALLOW | 2621783.215081 | 505957.248601 | 3238.806818 | 3 | 0.907613 | 2.333288 |
| SHALLOW | 2608217.4162 | 515001.114522 | 3238.806818 | 1 | 0.961259 | 1.745366 |
| MEDIUM | 2608217.4162 | 521784.013962 | 3238.806818 | 1 | 0.758419 | 1.937332 |
| MEDIUM | 2624044.181562 | 505957.248601 | 3238.806818 | 2 | 0.907011 | 1.654222 |
| MEDIUM | 2617261.282121 | 519523.047482 | 3238.806818 | 1 | 0.765774 | 1.410474 |
| DEEP | 2603695.48324 | 519523.047482 | 3238.806818 | 0 | 0.886192 | 1.291828 |
| DEEP | 2615000.315641 | 503696.282121 | 3238.806818 | 1 | 0.758782 | 1.266356 |
| DEEP | 2603695.48324 | 503696.282121 | 3238.806818 | 0 | 0.824622 | 1.261852 |

*Search Radius*
Radius of uncertainty search.
*Wells Within Radius*
Number of current wells located within search radius distance of proposed location.
*Quantile Score*
Estimated average percentile of site concentrations within search radius distance of proposed location.
*CV Score*
Estimated average coefficient of variation within search radius distance of proposed location.

# Appendix D. Fernald Optimization Results

This appendix includes the GTS optimization results at the Fernald DoE site computed by the ESTCP project team, as well as the summary reports (but not the attachments) submitted by the independent site analyst. In this case, the site analyst prepared two reports, one an evaluation of the GTS software, and the other an evaluation of the site using GTS and the data set he devised.

## FERNALD INDEPENDENT SITE ANALYST REPORTS

### Report #1. Evaluation of GTS Software

Geostatistical Temporal-Spatial (GTS Software)

Evaluation of GTS in General and Paducah Groundwater Case Study

May 13, 2010

Robert Johnson, Argonne National Laboratory

#### 1. Usability of the GTS software

**— How would you describe and rate general usability, including ease of use**

Apart from bugs encountered during the Fernald application, GTS was easily used. The interface made sense and was clear. There are some relatively minor suggestions on improving the user experience described below. Based on my experience, GTS's major benefits are the exploration that can be done with data sets once loaded (outlier searches, data gaps, time series plots, etc.) The major impediments to its use will likely be the following: 1) difficulty in setting up the software and acceptable input files, 2) run times for some of the steps, 3) "bugs" encountered during application, if my experience turns out to be representative, and 4) interpretation/reasonableness/defensibility of results.

Note that the Fernald data set only includes one analyte of interest, and so did not exercise all of GTS's functionality. Also, with the limited time at the end for doing the GTS analysis (combined with the length of time required for some of the runs), there wasn't the opportunity to completely explore the implications of the various user-adjustable settings on final results.

**-- Installation and set-up issues, including data import and accessibility**

Set up was a significant issue, primarily because we do not have administrative rights on our machines. In my case I was able, with the assistance of our system administrator, to install on my desktop but was unable to get GTS operational on my laptop (and abandoned trying once it was running on my desktop).

I struggled with data import. My struggles were two-fold: manipulating the Fernald data so that it satisfied GTS's data paradigm, and producing input files that GTS would accept.

The Fernald data has eccentricities that required attention. Examples include GeoProbe locations with discrete groundwater samples, well clusters, incomplete data fields, and negative results for uranium.

At Fernald a number of locations are revisited on a yearly basis and sampled using a GeoProbe, with discrete depth samples collected at several depths. Each year a location is visited, the resulting GeoProbe push has a slightly different name, and a slightly different location than preceding years. To allow a proper GTS analysis, the GeoProbe data had to be reworked in the following ways: 1) GeoProbe data for a particular general location were organized by vertical zone targeted, with the zones based on standard monitoring well nomenclature used at Fernald and the depth of the discrete samples – in some cases this resulted in multiple results for the same location/date/vertical zone; 2) vertical zones were assigned to GeoProbe results consistent with standard Fernald monitoring well nomenclature; and 3) all GeoProbe results from the same general location and vertical zone were assigned a common location name and common northing/easting.

The well clusters at Fernald presented a similar challenge to the GeoProbe data. A well cluster is a location that with multiple well screens that all share the same easting and northing but that are named differently depending on the vertical interval they are monitoring. Unfortunately the naming convention for well clusters did not lend itself to direct mapping to the standard Fernald monitoring well nomenclature for vertical intervals, and in some cases there was more than one screened interval at a well cluster for a given vertical monitoring interval. Consequently the well cluster data, like the GeoProbe data, were organized by location and by vertical zone targeted, and then unique location names assigned for each combination of location/vertical zone.

In retrospect, it is not clear if this was the correct way to structure the GeoProbe and well cluster data for Fernald. The goal was to allow either a 2D or 2.5D analysis with the same dataset. The assumption was that by breaking out data from different intervals at the same location and assigning different well names one would be able to evaluate the temporal redundancy of data sets easier, but this may have not been a good choice for the 2D spatial redundancy analysis. Conversely, if this had not been done, it's not clear that GTS would have broken out the temporal iterative thinning by vertical one.

The Fernald data included uranium values that were negative or zero. While these were always non-detect values, often times a reporting or detection limit was not provided. To ensure that GTS handled these properly a fictitious detection limit value was constructed based on reported non-detect results for those records that were missing detection limits and had non-detect flags.

The GTS manual provides definitions of the fields necessary for input, but it was not always clear which of those fields were absolutely essential versus useful but not essential, and which of those fields could tolerate missing values and which not. In the end, to load data that passed GTS muster, all fields with missing values were assigned a missing value placeholder.

**-- User interface and navigation issues**

In general the user interface was straightforward and readily understandable, usable, and navigable. I did notice some strange behavior at times that I could not consistently reproduce - when going back to the overview panel using the back button, at times there appeared to be an icon loading issue with the icons located along the right of the panel.

I did a lot of switching forward and backward within GTS to reset previous parameters, etc. At times I was not sure when I reset an earlier parameter value which updates or re-analyses had to take place to make sure the subsequent panels were in synch with the changes I had just made. A suggestion would be to grey out/render unavailable buttons that require something else to be updated when a change is made so that it is clear to the user which steps have to be redone.

**-- Helpfulness of the User's Guide in navigating and understanding GTS**

The User's Guide was, in general, easy to understand and follow. However there were many times when I found the brief description of what GTS was doing inadequate. I would strongly suggest adding appendices that provide technical detail and references, when appropriate, for the various analysis methods and approaches embedded within GTS.

**-- GTS saving and reporting capabilities**

These were all adequate based on my experience.

**-- GTS graphics capabilities**

In general, GTS graphics were great and very useful. A couple of suggestions relative to the maps:

- The user should be allowed to select the color used to portray shape file map features used as contextual overlays for GTS maps. In my case GTS assigned the same line color to several different polyline shape files that I had loaded – although I could figure out what the map meant since I knew the site, I'm sure it would have been cryptic to anyone else looking at it.
- The user should be allowed to change the drawing order of loaded shape files. This would eliminate the possibility of a filled polygon covering a polyline or point shape file that should have drawn on top.
- Interpolated maps showing concentrations should include a demarcation of areas predicted to exceed the regulatory standard.

**-- Encountered bugs, glitches, or other problems**

I encountered a number of problems as I worked through GTS, some of which were resolved by the GTS team, others of which are still outstanding. Below are the ones not resolved:

- If one creates a new GTS project and then tries to save it before loading data, an error message is thrown. A .gts file is created, but is not usable.
- My initial attempts at loading data files failed – no error messages were thrown, there was no indication that something was wrong with the files, but GTS did not allow me to work with the data. After much experimentation I found that if I completely filled all blank fields, the load would be successful.
- GTS currently does not provide a way of "clearing" a bad data load. It should. One is currently forced to start from scratch.
- I was unsuccessful in loading a boundary file. When I attempted to load a shape file (point or polyline), GTS through an error message. There was no documentation in the User's Guide that described exactly what the boundary file should contain or how it should be formatted.
- Under view network status, the report does not automatically reflect changes to protection status of wells when those changes are made. When one clicks "update" one is warned that this step shouldn't be necessary unless changes were made to data in earlier modules. It is not clear whether changing the protection status of wells is implemented if the update is not done (or vice versa – if the changed protection status of the wells is maintained if an update is done).
- Some the reports have headers that reference using the "NPL Dataset" – I assume this is not what is intended. Likewise the spatial redundancy reports refer to using "Iterative Thinning".
- The results of the spatial redundancy analysis as viewable via the map and associated data table did not match the results as viewed in the report for the 2D analysis (although they appeared to for the 2.5D analysis). Specifically, critical index values were sometimes significantly different, and consequently different sets of wells were identified as "redundant" depending on which GTS tool was used to view the results.

**-- Suggested improvements/refinements**

Suggested improvements/refinements beyond what has already been suggested:

- GTS should consistently "remember" the path name last used for file loading/saving so that the user doesn't have to constantly move to his/her working directory when interacting with files.
- The user should be allowed to selected time slice breakpoints. In the case of Fernald (and likely most sites with large numbers of monitoring wells), sampling is done on a rolling basis. There are definite date breakpoints between sampling cycles – it would make sense

for the user to have the ability to select these rather than to rely on GTS's ability to "find them" itself and potentially make a mistake. My own experience was that for some mean threshold values GTS did not "get it right".

- There really needs to be better guidance about proper selection of temporal and spatial bandwidths. These key parameters could potentially have significant impact on the final analyses, but the user is really left on their own. If nothing else, there should be discussion in the User's Guide about what the physical implications and interpretations are for small versus large bandwidths.
- The GTS user manual indicates that variograms are done for groups of wells, leaving the impression that the user might have the option of grouping wells by some factor. But there is no obvious place within the analysis to indicate an appropriate well grouping – is there none? If that's the case, then suggest that an option be provided (perhaps via a well list with check boxes or grouping numbers) to allow a user to do this. I'm not sure a variogram analysis is of much value if it is generalized across all wells.
- There are several different potential ways to look at temporal frequency requirements for monitoring programs. The primary approach used by GTS is to recreate historical time series plots through iterative thinning. One real measure of a monitoring program's performance is its ability to demonstrate confidently that contaminant concentrations for one well, or a group of wells, are either above or below regulatory guidelines at any given point in time. Recreating historical time series plots would seem to be a tangential way of measuring sampling frequency sufficiency from this perspective. Other approaches might include looking at trends relative to regulatory standards, looking at CV values in the context of regulatory standards, or incorporating fate and transport information in some qualitative or quantitative way. A suggestion would be to incorporate other measures of sampling frequency sufficiency so that a "weight of evidence" approach is possible (i.e., if a couple of different ways to look at the problem all lead to the same conclusion, then one would have more confidence that the conclusion was correct).

**2. Case study report:** Fernald

**— Electronic files including a saved project file and electronic (HTML/XML) versions of each of the GTS intermediate and final reports from the analysis**

Electronic files will be supplied separately.

**— A completed cost-savings file based on exporting results from GTS analysis and importing them into the cost-savings spreadsheet**

A cost-savings evaluation was not completed as part of this review.

**— Write-up of observations/notes regarding the case study analysis, particularly any problems or questions encountered**

A complete report summarizing the case study analysis will be provided as a separate document.

**— Summary of case study optimization findings**

For the Fernald south plume, the GTS analysis made use of 172 unique monitoring well/vertical zone combinations representing 130 unique locations (some locations had wells monitoring more than one zone represented in GTS as multiple wells at those locations).

Fernald currently uses a bi-annual sampling scheme for its monitoring wells. The GTS evaluation suggested that, on average across wells, an annual monitoring program would be sufficient.

The spatial redundancy evaluation in 2D provided conflicting results, depending on how the results were viewed. If viewed via a map and associated data tables, 31 out of 172 unique well/vertical zone combinations were flagged as redundant. If viewed via the exported results, 84 out of the 172 unique well/vertical zone combinations were flagged as redundant.

The spatial redundancy evaluation in 2.5D identified 25 wells across the three vertical zones as redundant via the map and associated data tables, as compared to 31 identified in the 2D model. Even though the number of wells identified as redundant was not that different between the 2D and 2.5D GTS analyses, there were significant differences in which wells were selected as redundant, suggesting that do a 2.5D analysis might be important to do in those cases where vertical monitoring zone distinctions are present.

In both cases (2D and 2.5D), the selection of redundant wells as portrayed in the provided map did not always make visual sense. In some cases relatively isolated wells were flagged as redundant while in other instances spatially clustered wells that were close together were left without any flagged as redundant.

GTS did not find any spatial data gaps in the 2-D analysis. When the analysis was done in 2.5D, GTS recommended new locations for two of the vertical zones, in one case three wells and in another five wells. These new locations, however, did not always make physical sense – for example, in the case of the zone with three new wells recommended, all three were immediately adjacent to an existing well.

**— Usefulness of GTS in performing the optimization**

All personal opinions here:

The primary utility of GTS as it currently exists is in its data exploration and presentation tools.

Monitoring well optimization is more of art than a science in that it requires an understanding of the characteristics and peculiarities of a site and its contaminants that are difficult to capture in a “black box” approach. Factors like whether residual contamination is hung up in subsurface clay lenses or is getting washed out of vadose zone pockets, the presence or absence of operating active treatment systems, longer-term and seasonal trends in water tables and flow, the presence or absence of natural attenuation, the original adequacy of the monitoring network and the placement of well screens relative to contaminant plumes – all of these and more are factors that need to be considered. I think a knowledgeable technical person, in the end, will always come to better conclusions than software alone – the role of software like GTS

should be to allow a knowledgeable technical person to come to those conclusions more quickly and confidently than they would have otherwise. The danger with software like GTS is that it potentially gives the impression that anyone can come to the correct conclusion if they just use the software.

I think one of the main stumbling blocks to the optimization routines in GTS is the time they consume, and their relative sensitivity to assumptions/parameters that could be potentially changed by the user. In an ideal situation a user should be able to explore the ramifications of changing spatial or temporal bandwidths, or spatial redundancy parameters, on GTS conclusions; however the length of time required by some runs makes that very difficult.

## Report #2. Application of GTS to the Fernald Site

### 1.0 Executive Summary

The purpose of applying GTS to the Fernald groundwater monitoring program was to provide an overall evaluation of GTS functionality, and to determine whether GTS could suggest modifications to the current monitoring regime that would reduce costs without compromising monitoring system performance, either by increasing the time between sampling events and/or eliminating redundant monitoring wells.

The Fernald analysis focused on the south plume and uranium data, with 172 monitoring points associated with 130 locations, including traditional monitoring wells, extraction wells, GeoProbe locations, and well clusters. Most of these locations have bi-annual sampling information extending back several years. In some cases, such as extraction wells, sampling frequency was as tight as every seven days. Overall, there were more than 10,000 records loaded into GTS.

GTS provides excellent data visualization/exploration tools; in particular its time series plots are invaluable for visually identifying non-detect values, outliers, and temporal trends.

The overall conclusion of GTS's iterative thinning algorithm was that for the south plume the average length of time between samples could likely be extended well beyond the current bi-annual protocol without affecting monitoring system performance. The average temporal frequency recommended by GTS was more than a year; given the obvious seasonality effects present in the Fernald data set for many wells, the recommendation would be to increase the time between sampling events to one year, with care taken that individual wells be sampled at approximately the same time each year so that cross-year comparisons will not be unduly affected by seasonal variations that have been observed in the Fernald data. This is an average conclusion; well-specific sampling frequencies recommended by GTS varied widely. The temporal bandwidth selection did have an impact on individual well recommendations, but did not appear to have a significant effect on overall recommendations (on average). The interpolation of temporal trends for wells with temporal data gaps was particularly sensitive to bandwidth selection (see Figure 12 for an example); the effect of this on individual well sampling frequencies was not explored, but one would expect the effect to be significant.

The overall conclusion of GTS's spatial redundancy analysis was that the monitoring program could be reduced by approximately 18% based on the 2D analysis. However this conclusion appeared to be very sensitive to whether the analysis was conducted in 2D or 2.5D, and to the spatial bandwidth selected. In addition, the wells identified as redundant did not always appear to make visual sense. Consequently the recommendation would be that a further evaluation of Fernald data be undertaken before implementing GTS's recommendations. The spatial data gap analysis also provided data on proposed new monitoring well locations; as with the redundancy analysis there was some question based on visual inspection as to the appropriateness of the recommended locations.

GTS provides a powerful tool for evaluating and potentially optimizing groundwater monitoring networks. Additional work should be done to validate the appropriateness and reasonableness of its spatial redundancy and spatial data gaps analyses. Because of the complexity of the temporal and spatial optimization analyses it performs, GTS is best used by environmental professionals who have a solid understanding of subsurface fate and transport phenomena and at least some background in statistical analyses.

## 2.0 Background

Many hazardous waste sites across the country, including some DOE facilities, have undergone remediation work with only residual difficult-to-treat contaminated groundwater remaining as a potential dose or risk issue. In these cases groundwater monitoring systems play the vital role of monitoring the contamination status of groundwater, providing an early warning if groundwater contamination appears to worsen or moves in unexpected ways, and verifying that cleanup goals have been achieved for specified locations if groundwater contamination levels decrease over time, and ultimately establishing that the site as a whole is in compliance with cleanup goals and monitoring can cease.

The challenge with monitoring system design is determining how many wells are required, where they should be placed, how frequently they should be sampled, and what analytes samples should be analyzed for. As time progresses and groundwater contamination evolves, monitoring networks need to be revisited to determine whether the original design is still "optimal" or should be revised to match changing groundwater conditions.

GTS (geostatistical temporal-spatial) software provides a statistical and geostatistical decision-logic groundwater monitoring optimization algorithm to assist in evaluating the appropriateness of existing long-term monitoring groundwater networks. GTS development has been funded by SERDP/ESTCP. The initial release of the software was made available in March, 2010 as part of an ESTCP project. As part of the ESTCP project, several federal sites were selected to serves as test sites for the application of GTS. One of those sites was the DOE Fernald site.

The Fernald site was a uranium metal production facility. Production activities at the site ceased in 1989. The 1990s were dedicated to site remediation activities, including the demolition and removal of buildings, the excavation of contaminated soils, and the construction of an on-site disposal facility as a repository for demolition debris and contaminated soils. In addition, historical site activities had resulted in groundwater contamination that had migrated off-site, with uranium the primary contaminant of concern. Active remediation (pump and treat) was

used to contain and treat contaminated groundwater. In the early 2000s, primary remediation activities at the site were completed, leaving only active groundwater remediation taking place along with its groundwater monitoring network.

This white paper describes the application of GTS to the Fernald groundwater monitoring network. The purpose of the application was to determine whether GTS could identify a useful reconfiguration of Fernald groundwater monitoring that would achieve the same monitoring performance at reduced costs by either eliminating redundant monitoring points and/or reducing monitoring frequency for selected wells. GTS also has the capacity for determining whether there are "holes" in a groundwater monitoring system; in the case of Fernald GTS was also used to evaluate whether new monitoring locations might significantly improve overall monitoring performance.

## 3.0 Fernald Site

The Fernald site occupies approximately 1,050 acres of land 18 miles northwest of Cincinnati, Ohio (Figure 1). The former production area occupied approximately 136 acres in the center of the site. Paddys Run flows north to south along the western boundary of the site. The Great Miami River flows generally north to south to the east of the site before turning to the southwest south of the site. The site is situated on top of glacier overburden, consisting primarily of clay and silt with minor amounts of sand and gravel that overlies the Great Miami Aquifer. The Great Miami Aquifer itself contains a non-continuous clay interbed that separates the Great Miami Aquifer into an Upper and Lower portion (Figure 2).

The Great Miami Aquifer is underlain by shale inter-bedded with limestone. Paddys Run has eroded the glacial overburden, exposing the sand and gravel that make up the Great Miami Aquifer. Groundwater flow in the Great Miami Aquifer, in general, is to the east, southeast, and south across the facility, towards the Great Miami River.

The site produced high purity uranium metal from 1952 through 1989. During that time period a significant amount of uranium was released to the environment, resulting in contamination of soil, surface water, sediments, and groundwater on and around the site. While there were other contaminants of concern besides uranium, uranium was by far the most significant and extensive contaminant of concern in environmental media, including groundwater.

During the 1990s and early 2000s, site remediation took place. High level wastes were shipped off-site for disposal. Low level contaminated material including building debris and soils were placed in an on-site disposal facility constructed for that purpose. The remediation process included deep and extensive excavations to remove soils contaminated with uranium that were believed to be sources for observed uranium groundwater contamination.

Groundwater contamination of the Great Miami Aquifer is believed to have resulted from infiltration of contaminated surface water through the bed of Paddys Run, the storm sewer outfall ditch, the Pilot Plant drainage ditch, and the waste storage area ditch. In addition, groundwater contamination resulted from the emplacement of uranium-contaminated wastes in disposal areas such as the South Fields, and subsequent uranium leaching. There is no significant groundwater contamination of the underlying bedrock. Uranium contamination is not uniformly distributed over the vertical profile of the Great Miami Aquifer. In general contamination levels are highest

in groundwater associated with the water table in the vicinity of original source areas, with the center of mass of uranium contamination becoming deeper as one moves down gradient with the plume, reflecting vertical gradients in groundwater flow and recharge of clean groundwater from infiltration through uncontaminated soils down gradient of old source areas.

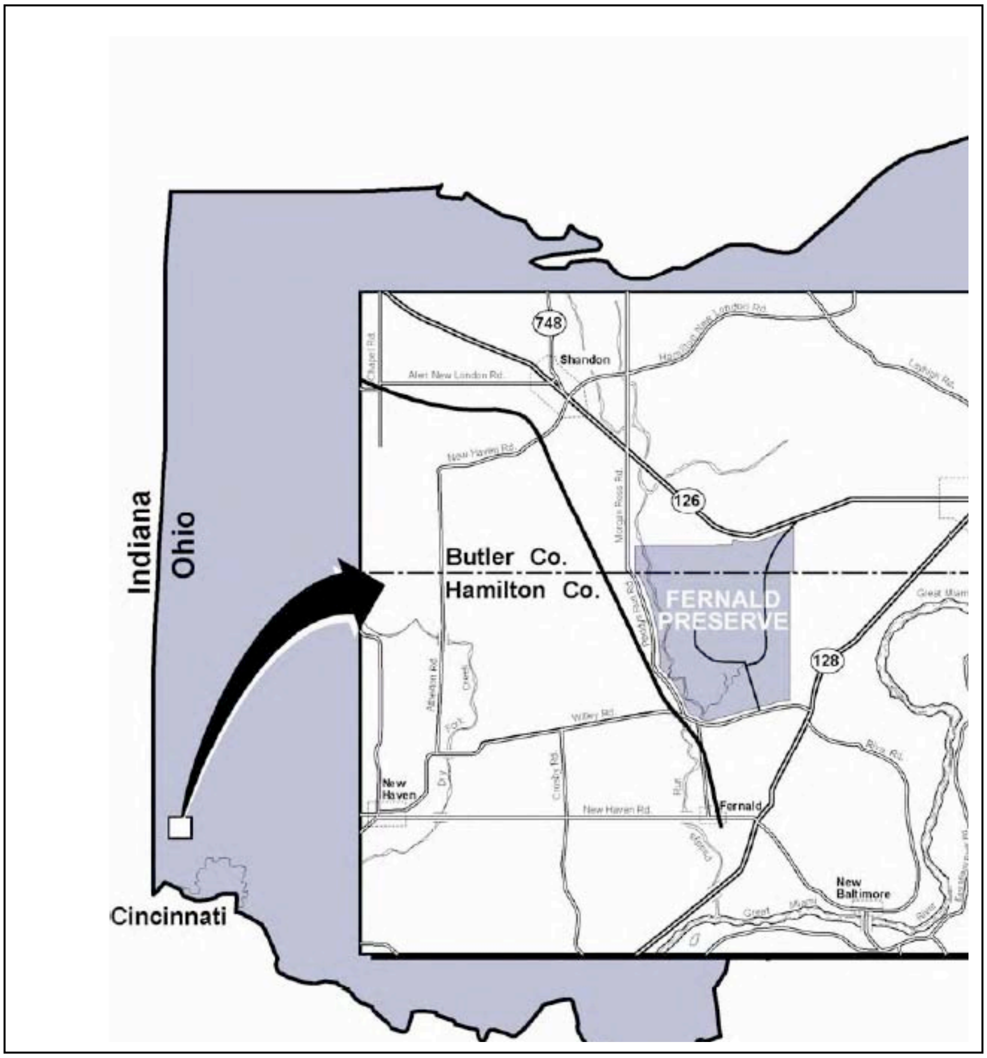



Figure 1 Location of the Fernald Site

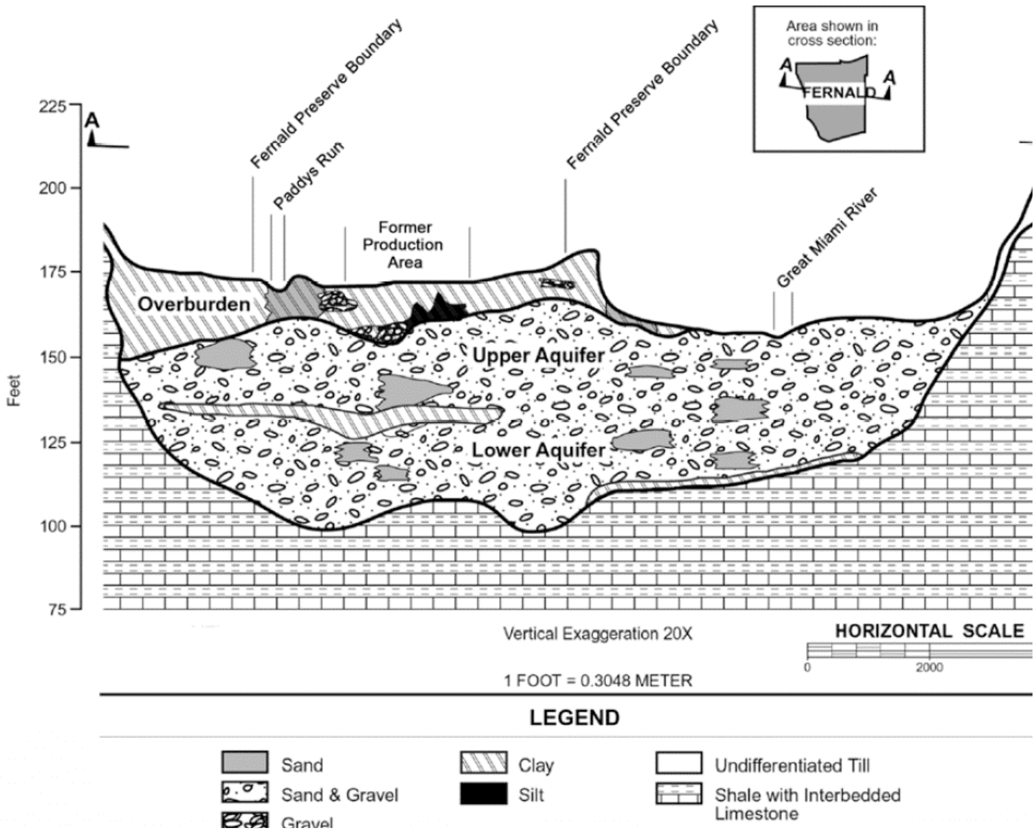



Figure 2 Schematic Cross Section of the Fernald Site

The primary contaminant of concern for groundwater is uranium. The cleanup standard for uranium is 30 ppb. Historical site production and waste disposal activities had resulted in a uranium groundwater plume exceeding cleanup standards that extended to the south off-facility. The ROD for the site called for remediation of groundwater via pump-and-treat. A pump-and-treat system was installed in the 1990s. The pump-and-treat system originally installed has been modified over the years to enhance its performance, including the use of re-injection wells and additional extraction wells. Figure 3 shows the locations of extraction wells in operation in 2007.

Contaminated soil (source) removal, the elimination of other contamination sources, and the operation of the pump-and-treat system has had a significant impact on the footprint of the groundwater plume over the years; however there remain several distinct areas where groundwater uranium levels persist above the cleanup standard. These include the south plume, which is directly south of the facility fence line, the south field plume, which is just north of the southern facility fence line, and the waste storage area plume, which is in the central portion of the site immediately to the west of the former production area.

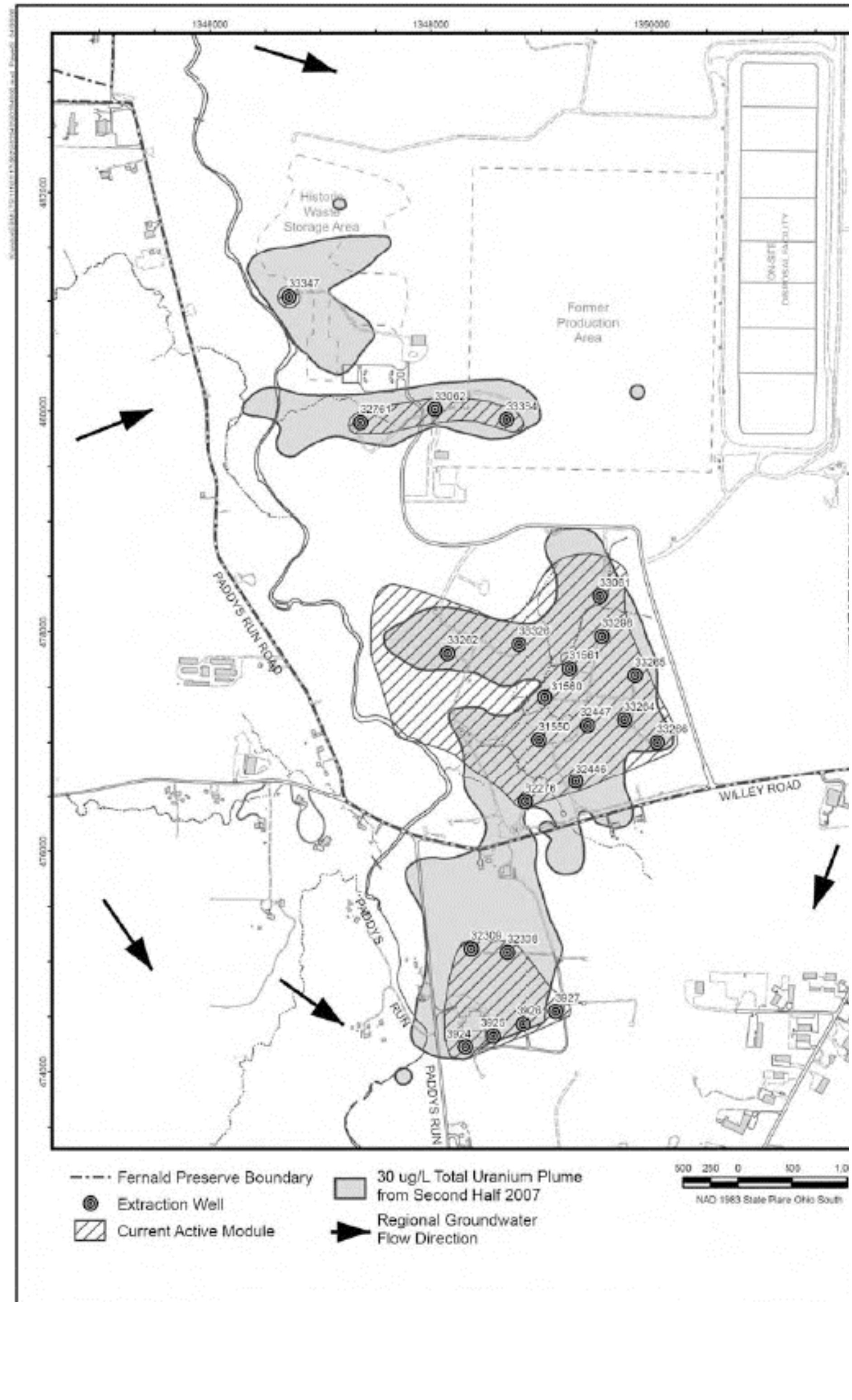



Figure 3 Location of Extraction Wells Operating in 2007

The Fernald Groundwater Certification Plan (2005) established the programmatic strategy for certifying completion of the aquifer remedy. The Integrated Environmental Monitoring Plan (IEMP, 2006) details monitoring requirements, including those for groundwater. As part of the comprehensive groundwater monitoring program, approximately 140 wells are monitored for water quality, and 170 wells for groundwater elevations to monitor groundwater flow directions. Groundwater samples from all wells monitored for groundwater quality are analyzed for uranium; samples from selected wells are also analyzed for other groundwater constituents that reflect very localized concerns for other contaminants.

Sampling frequency varies. For wells that are part of the groundwater remediation system, samples are collected monthly. Most other wells are sampled bi-annually. Because of the large number of wells, sample collection is not synoptic; rather there is a rolling sampling protocol that cycles twice a year through the required set of monitoring wells. Monitoring focuses on the three distinct plumes described previously.

Fernald's groundwater monitoring network includes a variety of types of wells, including single-screened wells, wells clusters with screens at different vertical intervals, and GeoProbe locations where direct push methods are used to obtain discrete groundwater samples from different depths. GeoProbe data collection primarily focuses on the south plume, which is on private property. For wells with screens, screen placement and length can vary depending on the vertical zone that is targeted (Figure 4). Screened intervals can target perched waste conditions (Type 1 wells, 2 – 10 ft. screens), screened intervals that target the water table/vadose zone interface (Type 2 wells, 15 ft. screens), screened intervals that target the vertical middle of the Upper Great Miami Aquifer (Type 6 wells, 10 – 15 ft. screens), screened intervals targeting the bottom of the Upper Great Miami Aquifer (Type 3 wells, 10 ft. screens), wells that target the full vertical profile of the Upper Great Miami Aquifer (Type 8 wells, variable screen length), and wells that target the lower Great Miami Aquifer (Type 4 wells, 10 ft screen).

## 4.0 GTS Methodology

The GTS software is designed for optimizing spatially and temporally groundwater monitoring networks. The GTS methodology consists of several sequential steps, including:

- Prepare. Within Prepare, existing historical monitoring data (analytical and potentiometric) are loaded and used to create a GTS database. Additional relevant site information is associated with the project (i.e., boundary, mapping layers, etc.). An initial data outlier analysis is also conducted.
- Explore. Within Explore, data sets are summarized, COC's are selected for analysis (if more than one contaminant of concern was included in the analytical data), vertical attributes are assigned to data records.

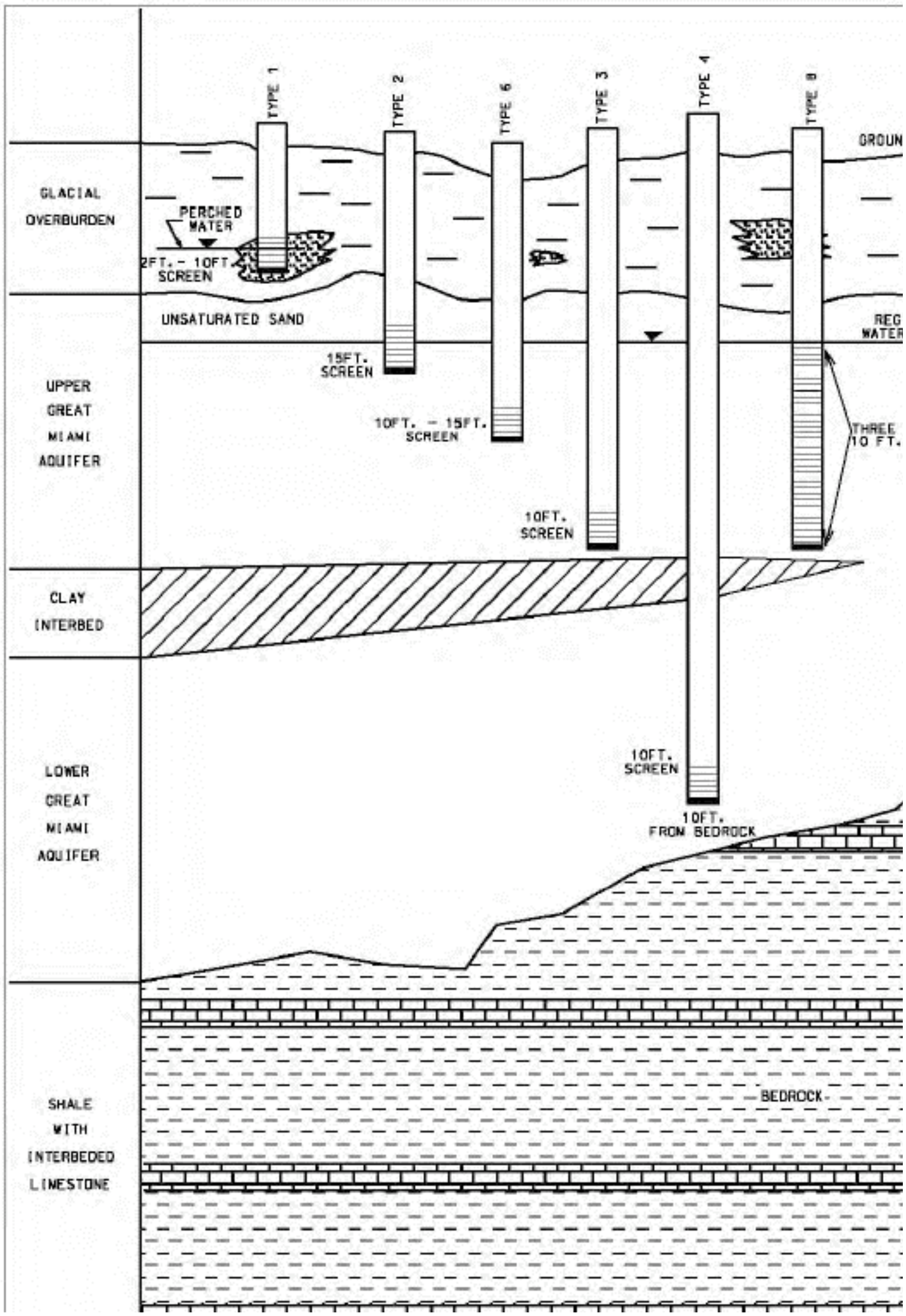



Figure 4 Fernald Monitoring Well Types

- Baseline. Within Baseline, baseline temporal and and spatial trends are developed from historical data, including potentiometric surfaces and maps of plume extent. These baselines trends/surfaces are important for the subsequent Optimize step, since they represent the "reality" that one attempts to re-create using a subset of the monitoring locations and/or different monitoring frequencies.
- Optimize. Within Optimize, sampling frequency is evaluated to determine if sampling frequency can be reduced without compromising monitoring performance. The spatial network of wells is also evaluated with a similar goal in mind – to determine if a smaller subset of monitoring locations could provide equivalent monitoring performance. Finally, the optimize step determines whether there are spatial locations where an additional monitoring well would add significantly to the overall performance of the monitoring system.
- Predict. Within Predict, new data are tested against historical data sets to determine if they are consistent with past trends/spatial maps so that anomalies or changes can be identified.

The Fernald application of GTS exercised every GTS step with the exception of Predict. Because of the bulk of the monitoring is dedicated the largest plume, the South/South Fields plume, the GTS analysis also focuses on this area.

## 5.0 Fernald Data Sets

Historical groundwater monitoring data sets were provided by DOE LM for the Fernald site in May, 2008. These data included both analytical groundwater results and depth-to-water-table measurements. As provided the data included some records that contained fields with data formatting issues; these data problems were addressed and corrected as necessary to allow loading into an Access database. The data were then reformatted to match GTS formatting requirements, and data exported to an Excel spreadsheet to facilitate loading into GTS. Data records with an original QC flag of "R" (or rejected) were deleted from this export as well as records for wells without coordinate information. Wells without coordinate information correspond to private wells monitored off-premises; monitoring commitments for these wells would preclude them from "optimization," so their absence from the GTS evaluation is not an issue.

The resulting analytical data file contained around 46,000 records from January, 1997 through January, 2008, representing 719 uniquely named monitoring locations. The focus of the GTS Fernald evaluation was on uranium; of the 46,000 records available, approximately 18,500 were uranium results for groundwater. Of these, the primary focus was on locations currently monitored for uranium (a number of wells have been abandoned since 1997). This subset of wells can be furthered broken down as follows:

- Extraction wells. Extraction wells are part of the groundwater remediation system and are, in general, sampled monthly. There are 23 wells monitored in this fashion in 2007,

including wells 3924, 3925, 2926, 2927, 31550, 31560, 31561, 32276, 32308, 32309, 32446, 32447, 32761, 33061, 33062, 33262, 33264, 33265, 33266, 33298, 33326, 33334, and 33347. The initial well digit indicates the type of well (e.g., wells i.d.'s starting with a "3" were Type 3 wells).

- GeoProbe locations. 27 locations in 2007 underwent GeoProbe data collection. This primarily focuses on the south plume, with groundwater samples typically collected at 10 ft. intervals for each location to provide vertical information on the location of the uranium plume.
- Regular Monitoring Wells. There were 134 monitoring wells in 2007 that had analytical data for uranium. These included:
    - Two private wells
    - 76 Type 2 wells
    - 37 Type 3 wells
    - Two Type 4 wells
    - 17 Type 6 wells
- Well Clusters. There were fifteen 15 well clusters in 200 that had analytical data for uranium.

The analytical data available for Fernald had to be modified to fit GTS input requirements. The modifications included the following.

- Data qualifiers were normalized to match GTS requirements.
- Although a significant number of uranium analytical results were flagged as non-detects, method detection limits and/or reporting limits were typically not provided. For these records the MDL (a GTS requirement for results flagged as non-detects) was set to the reported result. If the reported result was negative, the MDL was set to the absolute value of the MDL.
- The monitoring well data for Fernald included GeoProbe locations. In some cases GeoProbe groundwater data collection for a particular location only took place once. In other cases, however, a particular location was revisited over the years for additional GeoProbe data collection. In these cases, while the cores would be close together their locations were not exactly the same; each GeoProbe push was assigned a unique identifier. To accommodate GeoProbe information in GTS, GeoProbe locations where data were collected across years were assigned a unique identifier that was applied to all GeoProbe data collection in the vicinity of that location. In addition, the coordinates for all GeoProbe pushes in the vicinity of a particular location were standardized to one common easting and northing. To further facilitate GTS analysis, the GeoProbe data for a particular "location" were then further parsed, with GeoProbe depths loosely matched against Fernald's standard monitoring well classification, with separate location identifiers assigned for each classification category.
- The monitoring well data for Fernald included well clusters with individual wells screened over different intervals. Individual wells for a particular cluster already shared common easting and northing values, but had unique identifiers. As with the GeoProbe locations, well identifiers for well clusters were initially modified so that all wells within a cluster shared the same identifier, and then renamed so that interval depths roughly corresponded to Fernald's standard monitoring well classification.

- A number of the data fields from Fernald had missing data. In some cases GTS required complete data sets (for example, WTCCODE which corresponds to monitoring well type). Missing data fields were filled in as necessary to satisfy GTS data import requirements.

The 18,500 analytical results were further restricted to just those wells that were monitored in 2007. Although the data set included 2008 analyses for a small number of wells, these results were not included in the GTS analysis. Finally, there were a number of GeoProbe records where a sample depth was not provided. These were also deleted from the GTS analysis.

Finally, the analytical data set was further restricted to those monitoring locations associated with the southern plume, by far the largest and most significant plume on site. This reduced the analytic data set to 10,312 uranium records. Note that in some cases these records included field duplicate results.

In addition to laboratory data, DOE provided depth to water table information as well. This was formatted to fit GTS requirements and loaded. The set of wells for which depth to water table measurements are made at Fernald is larger than those sampled. In addition, some wells that are sampled (e.g., extraction wells) do not have depth to water table information. Consequently not all analytical records loaded into GTS were paired with depth to water table information; likewise, not all depth to water table data were assigned to monitoring wells in GTS.

## 6.0 Results and Discussion

There are three distinct uranium plumes present at the Fernald site (Figure 3), two small plumes west of the former production area and one larger plume in the southern part of the facility. The GTS analysis focused on the largest of these three, the combination of the South Field and South plume. Historically this was one plume; in recent years, after source removal and operation of the pump and treat system, the one large plume has resolved into two distinct areas where contamination remains significantly above the cleanup requirement for the site.

### 6.1 GTS Prepare

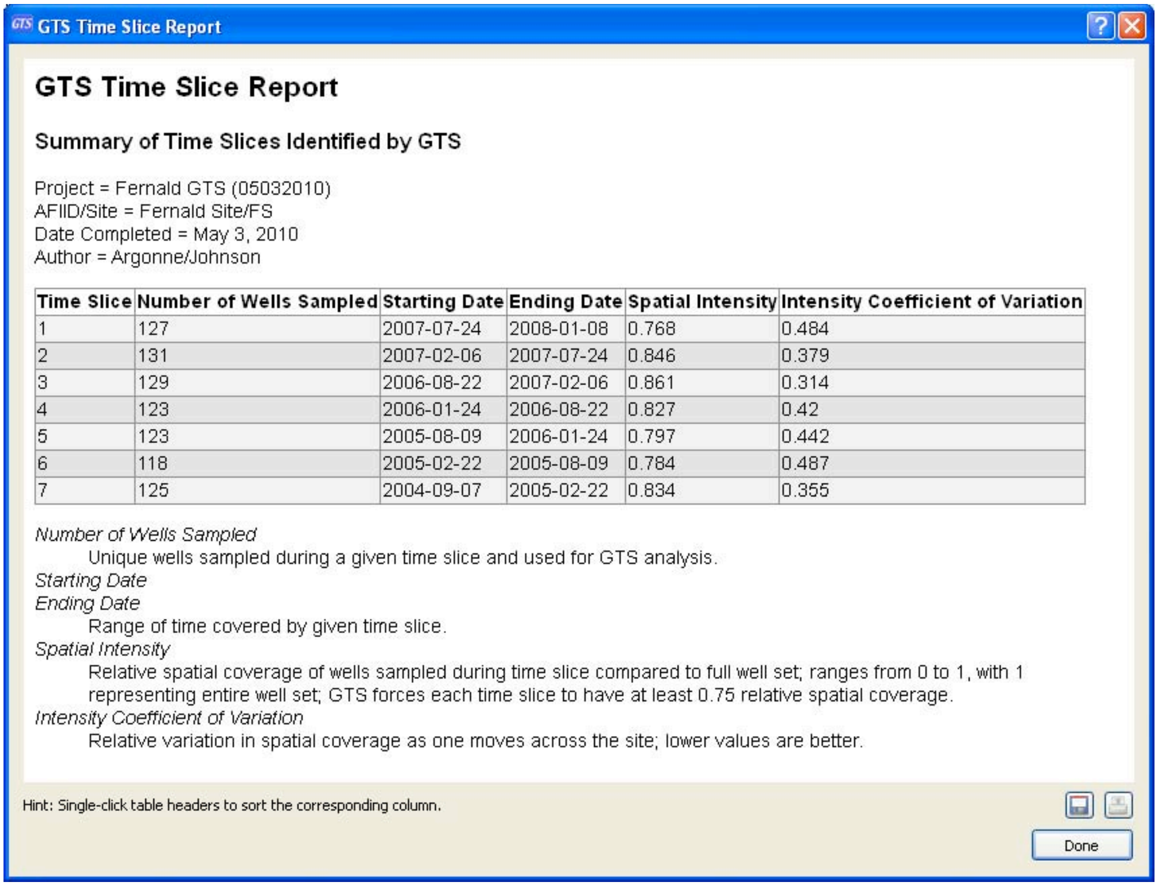
The GTS Prepare step focused on the 10,312 uranium analytical records corresponding to the largest plume. The analytical data was formatted per GTS requirements and loaded, as was a separate water table elevation file. As previously noted, not all analytical results had corresponding water table elevation data; likewise not all water table elevation records had corresponding uranium analytical results.

The data were "checked" via GTS. A number of recommended data fields contained missing information; however these missing data were not critical to the GTS analysis and represented the actual state of the Fernald data set. The discrepancy report was also reviewed; a large number of "discrepant" data were identified. The bulk of these pertained to missing data results or partially completed fields. None were deemed significant to the GTS analysis.

The “Calculate Analysis Variables” was run several times with different “mean threshold” settings, with the following results:

- Mean threshold = 0.90. Four time slices from 2002 though 2007 with between 148 and 155 wells sampled per time slice. One time slice per year.
- Mean threshold = 0.85. Seven time slices from 2002 though 2007 with between 129 and 149 wells sampled per time slice. One time slice per year.
- Mean threshold = 0.80. Seven time slices from 2003 though 2007 with between 120 and 149 wells sampled per time slice.
- Mean threshold = 0.75. Seven time slices from 2004 though 2007 with between 118 and 131 wells sampled per time slice. Two time slices per year with the exception of 2004.
- Mean threshold = 0.70. Same result.
- Mean threshold = 0.65. Same result.
- Mean threshold = 0.60. Same result.
- Mean threshold = 0.55. Same result.
- Mean threshold = 0.50. Seven time slices from 2005 though 2007 with between 92 and 123 wells sampled per time slice. Four of these time slices occurred in 2006.

Based on this analysis, the default mean threshold of 0.75 was selected for data processing since this resulted in time slices that most closely mirrored the bi-annual sampling regime present at the site. Figure 5 shows the results.


GTS Time Slice Report

## GTS Time Slice Report

### Summary of Time Slices Identified by GTS

Project = Fernald GTS (05032010)
AFIID/Site = Fernald Site/FS
Date Completed = May 3, 2010
Author = Argonne/Johnson

| Time Slice | Number of Wells Sampled | Starting Date | Ending Date | Spatial Intensity | Intensity Coefficient of Variation |
|---|---|---|---|---|---|
| 1 | 127 | 2007-07-24 | 2008-01-08 | 0.768 | 0.484 |
| 2 | 131 | 2007-02-06 | 2007-07-24 | 0.846 | 0.379 |
| 3 | 129 | 2006-08-22 | 2007-02-06 | 0.861 | 0.314 |
| 4 | 123 | 2006-01-24 | 2006-08-22 | 0.827 | 0.42 |
| 5 | 123 | 2005-08-09 | 2006-01-24 | 0.797 | 0.442 |
| 6 | 118 | 2005-02-22 | 2005-08-09 | 0.784 | 0.487 |
| 7 | 125 | 2004-09-07 | 2005-02-22 | 0.834 | 0.355 |

*Number of Wells Sampled*
Unique wells sampled during a given time slice and used for GTS analysis.
*Starting Date*
*Ending Date*
Range of time covered by given time slice.
*Spatial Intensity*
Relative spatial coverage of wells sampled during time slice compared to full well set; ranges from 0 to 1, with 1 representing entire well set; GTS forces each time slice to have at least 0.75 relative spatial coverage.
*Intensity Coefficient of Variation*
Relative variation in spatial coverage as one moves across the site; lower values are better.

Hint: Single-click table headers to sort the corresponding column.

Done

Figure 5 GTS Time Slice Report

The analysis relied on GTS to calculate a convex hull around the available monitoring data (i.e., no boundary file was loaded). Four shape files were loaded to facilitate map interpretation: streams, roads, fence lines, and the footprint of the OSDF. Figure 6 shows the locations of the wells and the convex hull GTS constructed around the wells.

The next step for GTS data preparation was outlier identification. GTS breaks this into temporal and spatial outlier identification. Performing the temporal outlier analysis, GTS identified the following wells/dates/data points as outliers and suggested they be removed from the analysis:

- GeoProbe location 12194, depth intervals associated with the water table. In general uranium values for samples from the vicinity of the water table were around 10 ppm, but one was listed as a non-detect on 10/06/03. Record flagged as an outlier.
- Monitoring well 2125. Historically this well has returned uranium results around or less than 10 ppm, but on 10/21/97 a uranium value of 88 ppm was reported. Record flagged as an outlier (shown in Figure 7).

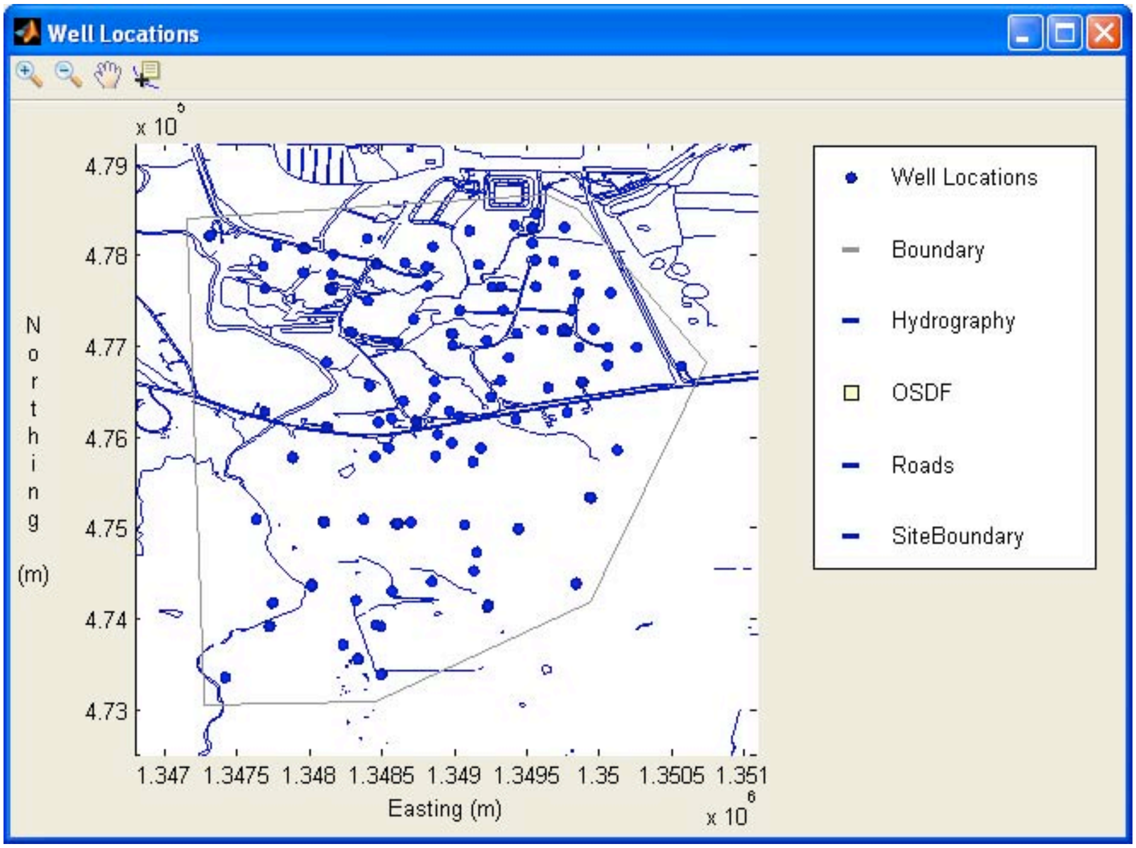



Figure 6 Well Locations and Convex Hull

- Monitoring well 2396. Historically this well has returned uranium results around or less than 1 ppm, but on 11/19/01 a uranium value of 3.43 ppm was reported. A subsequent sample on 2/08/02 also yielded a result higher than the historical average (1.5 ppm), consequently the 3.43 ppm was not flagged as an outlier.
- Monitoring well 2550. Historically this well has returned uranium results between 40 and 80 ppm, but on 11/05/99 a non-detect was reported. Record flagged as an outlier.
- Monitoring well 2897. Historically this well has returned uranium results around or less than 1 ppm, but on 2/09/00 a result of 3.3 ppm was reported. This behavior was consistent with that observed in well 2396 and consequently the record was not flagged as an outlier.
- Monitoring well 3015. Historically this well has returned uranium results around 1 to 2 ppm, but on 8/4/97 a result of 149 ppm was reported. Record flagged as an outlier.

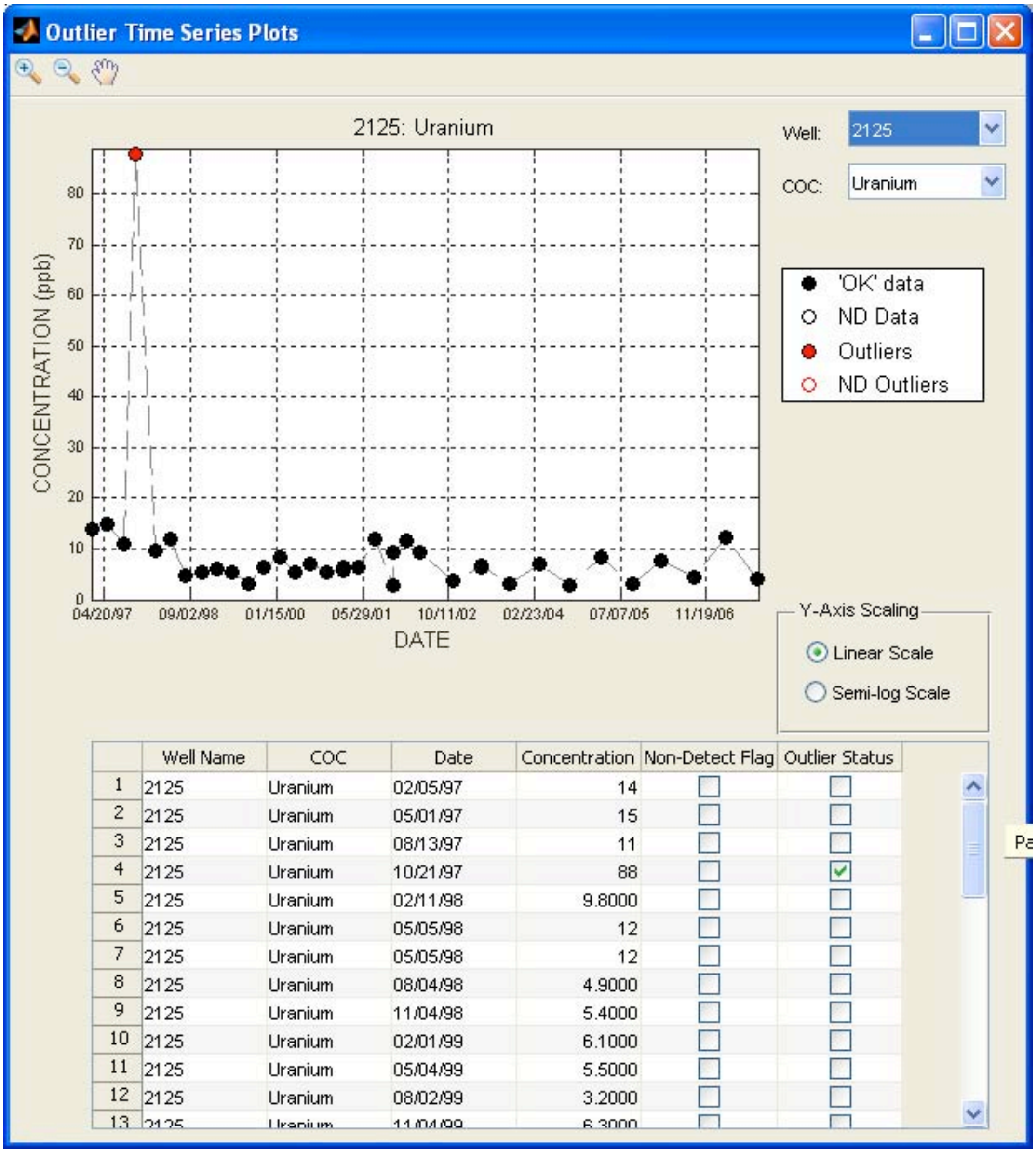



Figure 7 Example Outlier for Well 2125

- Extraction well 33264. Historically this well has shown a decreasing trend in uranium concentrations, with the most recent values around 70 ppm. However on 9/23/02 a result of 364 ppm was reported. This value was not that different, however, from several other values from that time frame. Record was not flagged as an outlier.
- Extraction well 33265. Historically this well has shown a decreasing trend in uranium concentrations, with most recent values around 18 ppm. However on 1/02/06 a result of 96 ppm was reported that was approximately 3 times as great as other results from that time period. Record flagged as an outlier.

- Extraction well 33266. Historically this well has shown a decreasing trend in uranium concentrations, with most recent values around 28 ppm. However the intial values reported on 05/23/05 were around 60 ppm. These were not inconsistent with the historical trend for this well and so these records were not flagged as outliers.
- Monitoring well 3387. Historically this well has reported uranium results around or less than 5 ppm. However, on 9/06/00, a uranium result of 42 ppm was reported. Record was flagged as an outlier.
- Monitoring well 3550. Historically this well has reported uranium results around or less than 3 ppm. However, on 11/05/99 a uranium result of 58 was reported. Record was flagged as an outlier.
- Monitoring well 3552. Historically this well has reported uranium results around or less than 1 ppm. However two results in 2004 were 7.1 and 3.6 ppm, respectively. On these dates there were also field duplicates collected. The duplicate results were consistent with historical trends. Consequently these two values were treated as outliers.
- Extraction well 3926. On 7/24/00, a non-detect uranium value was reported. Other results from this time period were consistently above 20 ppm. Record flagged as an outlier.
- Monitoring well 4398. Historically this well has reported uranium results that were either non-detects or less than 1 ppm. However on 1/6/99 a uranium value of 25 ppm was reported. Record flagged as an outlier.
- Monitoring well 62433. In recent history this well has reported uranium results that are around 200 – 300 ppm. However on 3/6/01 a uranium result of 846 ppm was reported. Although high, this result was not completely inconsistent with other values from that time period. Record was not flagged as an outlier.

GTS performed a spatial outlier analysis and did not identify any spatial outliers.

### 6.2 GTS Explore

The GTS explore module allows the user to view maps and temporal plots of uranium results for individual wells. An example is shown in Figure 8, which displays the median deciles for uranium with well locations color-coded by the decile associated with their median value. One of the primary purposes of this step is to identify the primary contaminants of interest from a monitoring optimization perspective. Since the Fernald implementation of GTS is only concerned with uranium, the majority of the functionality under the explore module did not apply.

The final step in the explore module is to determine whether the analysis should be 2D or 2.5D. In the case of 2.5D, monitoring wells are categorized and analyzed by relevant vertical zones. In the case of Fernald, there are five general zones – the water table, the middle of the upper GMA, the bottom of the upper GMA, the lower GMA, and bedrock. For the southern portion of the uranium plume, only the water table, the middle, and the bottom portion of the GMA have a significant number of pertinent monitoring wells. In a 2D analysis, all wells and associated data are considered and the vertical monitoring zone is neglected.

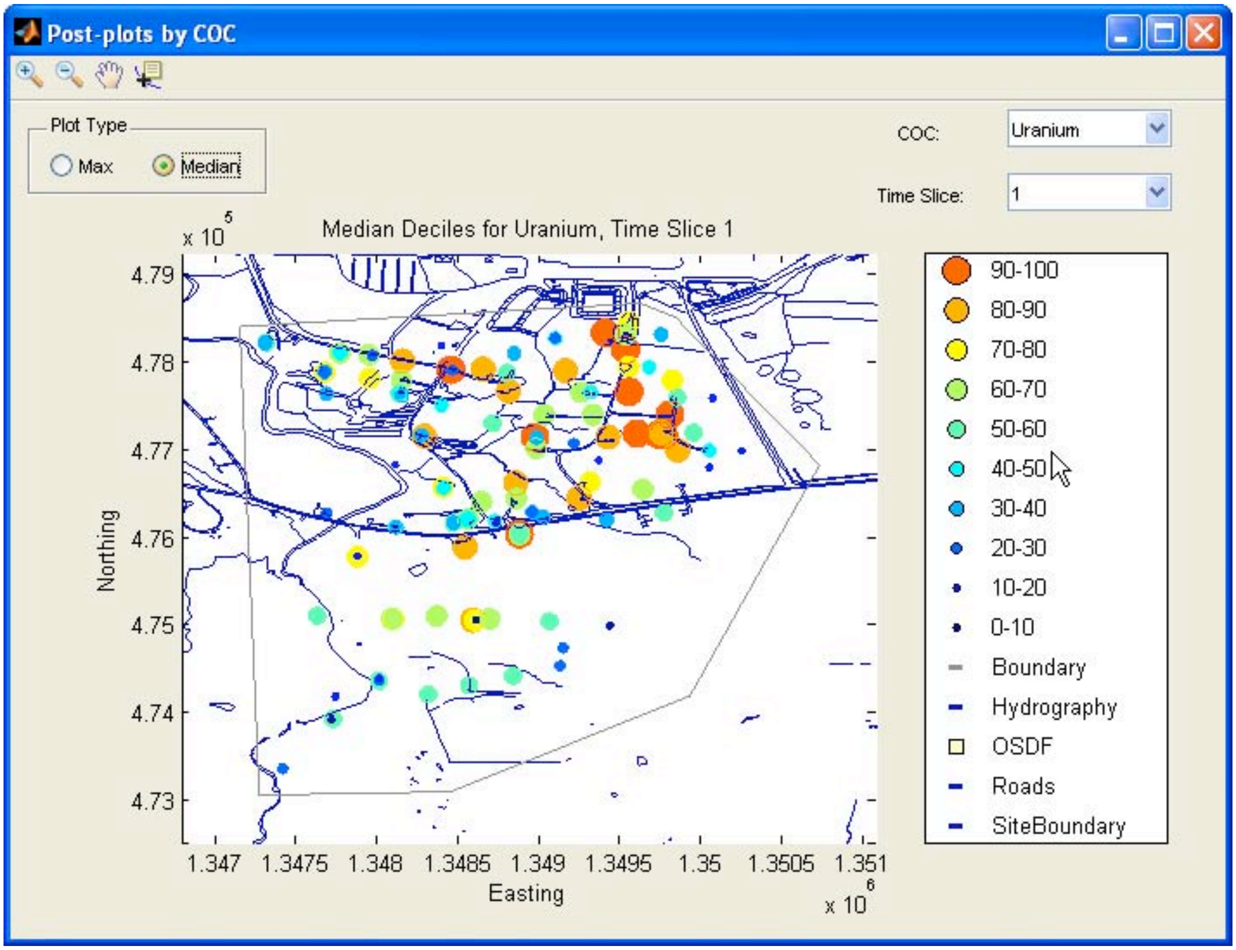



Figure 8 Median Decile Map for Uranium

To assist in making a determination of whether a 2D or 2.5D analysis is appropriate, and to help in selecting the appropriate vertical horizons if a 2.5D analysis is selected, GTS summarizes data availability by vertical zone, and provides concentration box plots and relative variograms for each horizon. Figure 9 shows this summary, while Figure 10 shows the box plots and variograms for the Fernald data. A relative variogram provides a sense of the degree of spatial autocorrelation present; if spatial autocorrelation differs significantly from horizon to horizon and there is sufficient monitoring information for each horizon, then a 2.5D analysis might appropriate.

In the case of the Fernald data, a 2D GTS analysis was conducted. As part of the 2D analysis, private wells (1 well) and wells monitoring the lower Great Miami Aquifer (2 wells) were “deleted” using the merge/delete horizons panel.

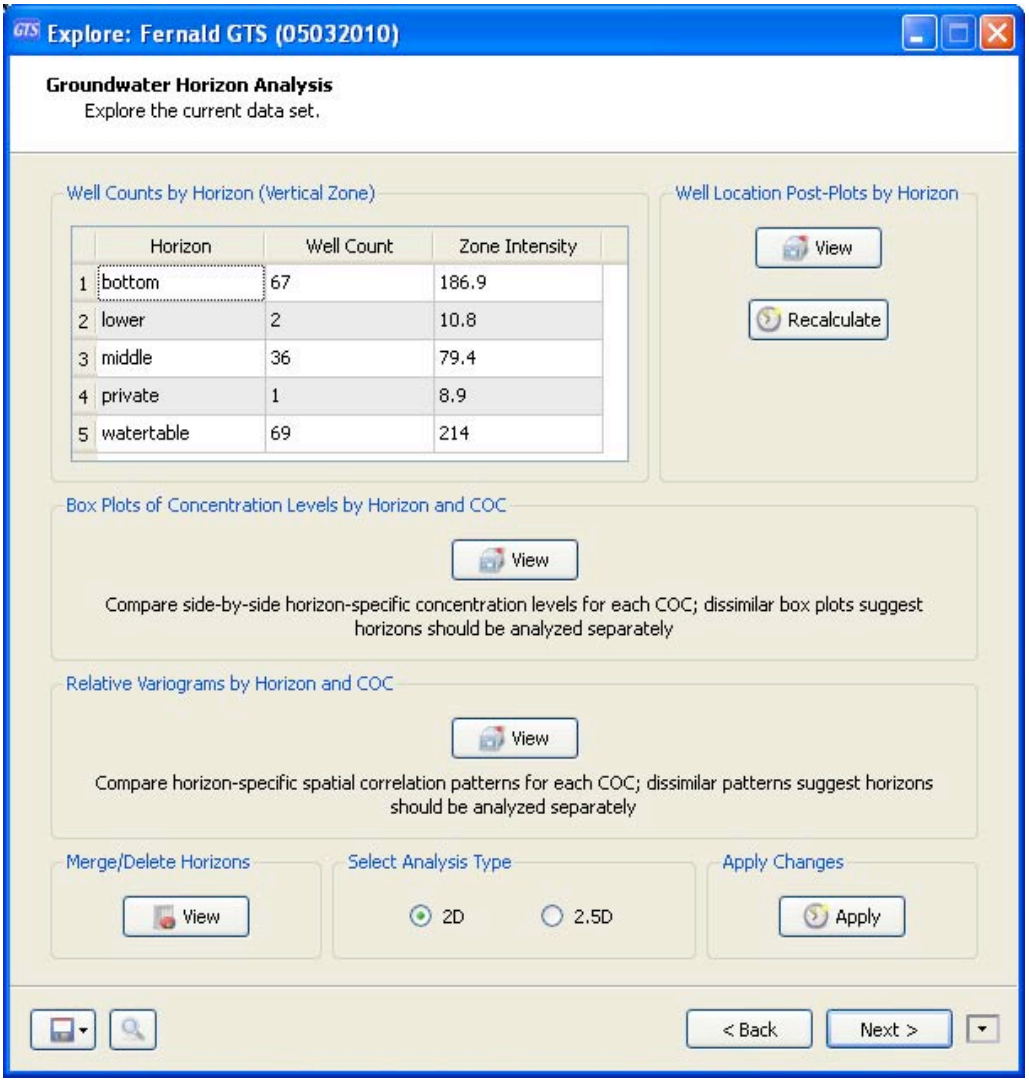
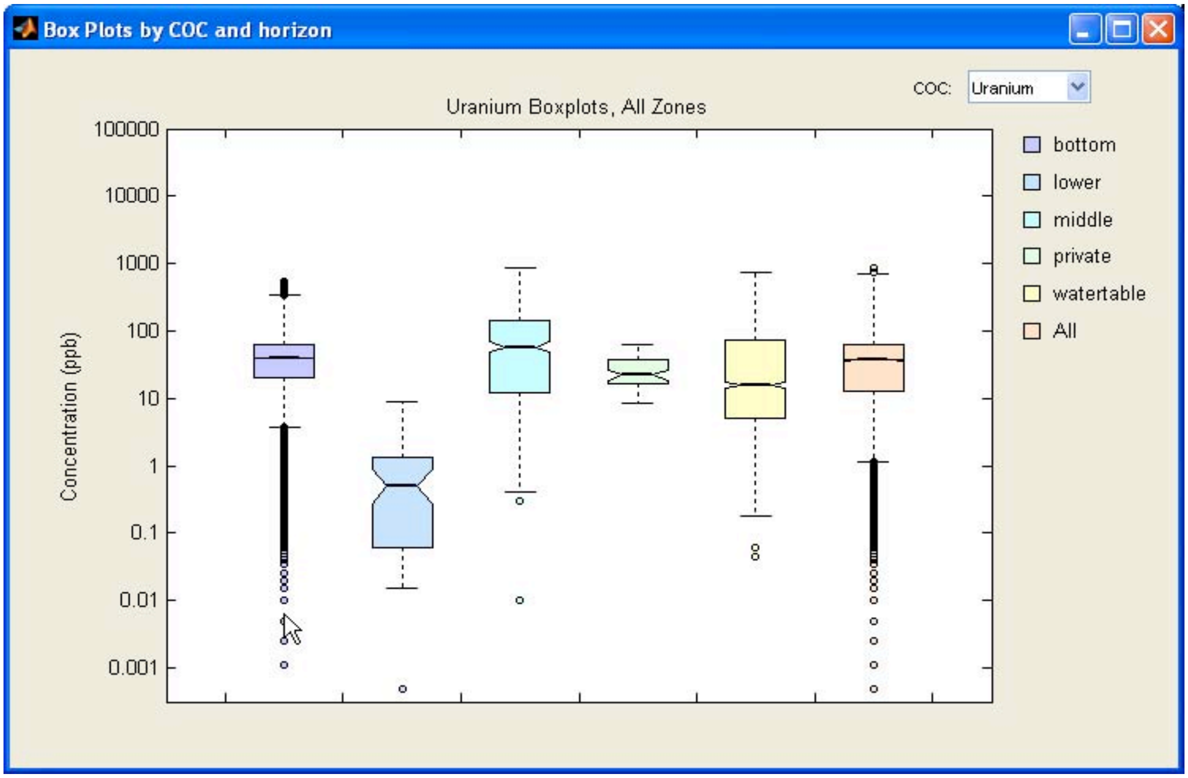



Figure 9 Well Number Summaries by Horizon

## 6.3 <u>GTS Baseline</u>

The purpose of the GTS baseline module is to establish temporal and spatial trend baselines that will later be used for evaluating the performance of alternative, “optimized” monitoring strategies.

The first step in the baseline process is to identify those wells that are “protected” from an optimization perspective. These are wells that, for whatever reason, require monitoring whether one considers those data redundant or not. In the case of the Fernald site, all extraction wells were marked “protected” because monthly monitoring is a requirement for those wells (Figure 11).



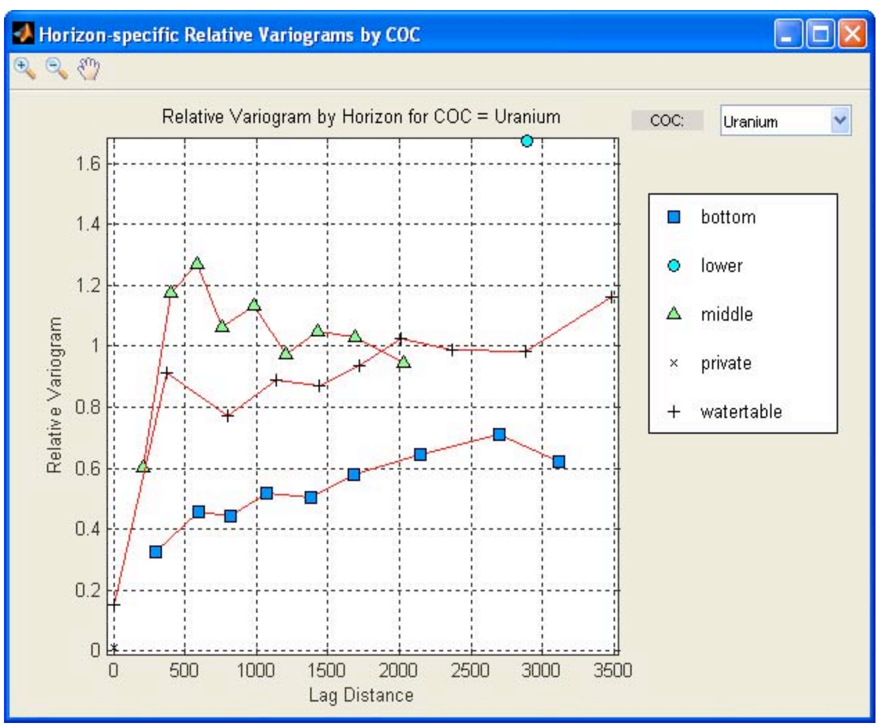




Figure 10 Concentration Box Plots and Variograms by Horizon

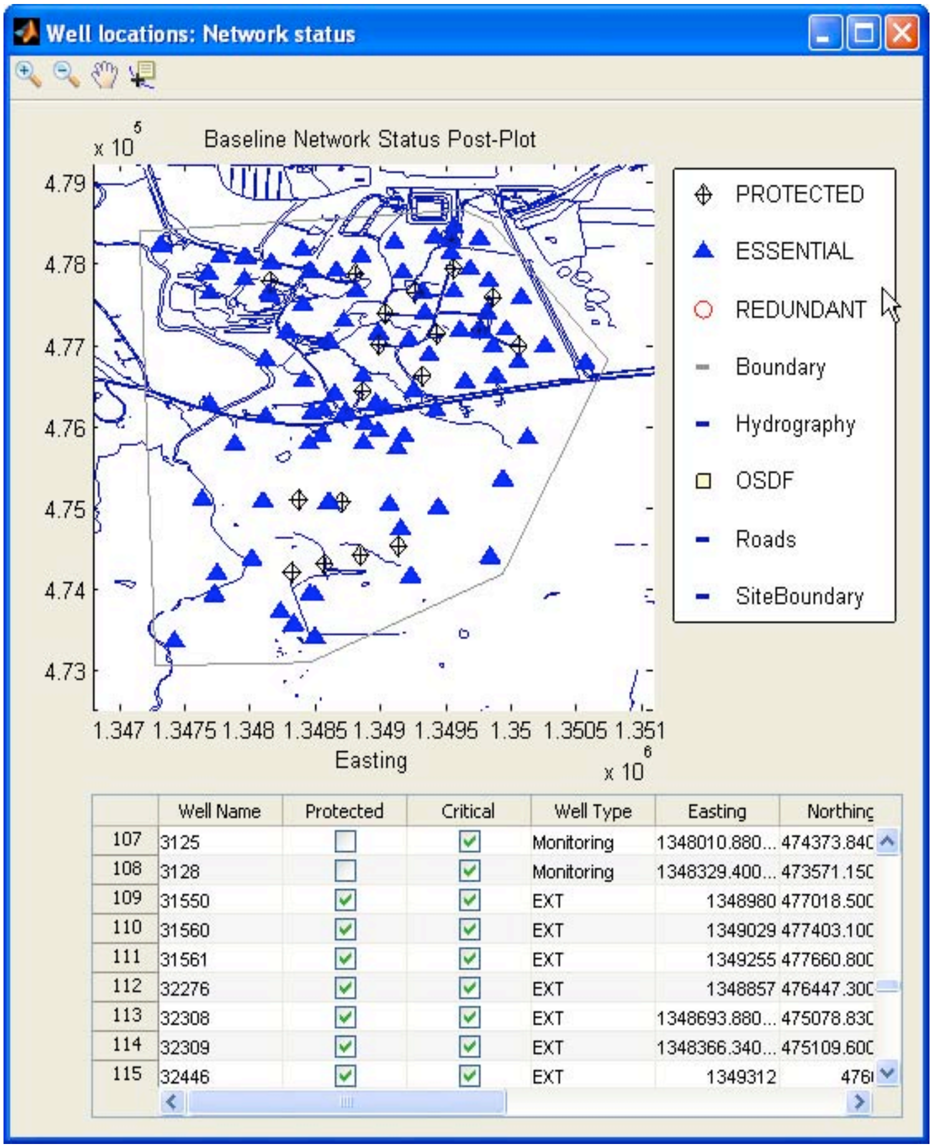



Figure 11 Protected Wells for Fernald GTS Example

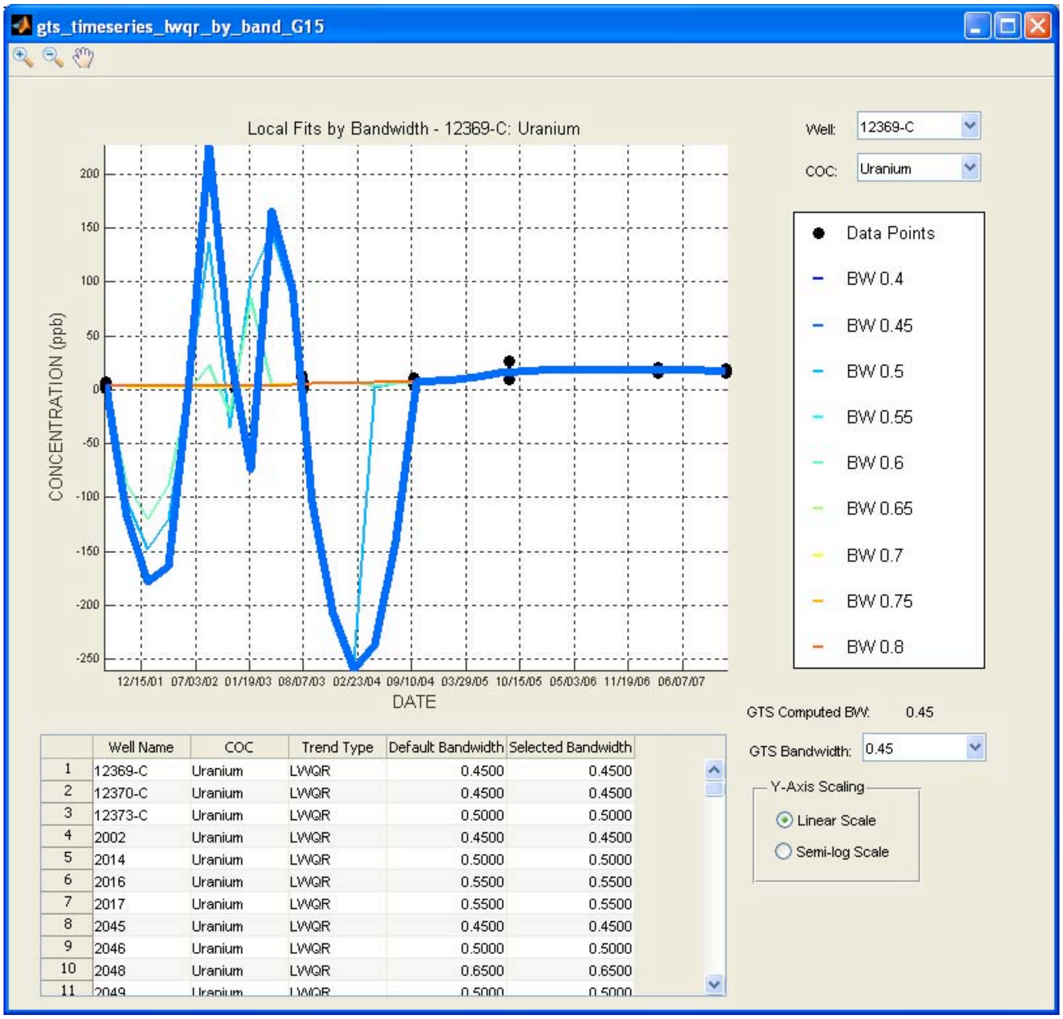
The second step is to determine whether wells have sufficient data to support temporal trend construction, and in particular, if large temporal data gaps exist that might complicate temporal trend construction. In the case of the Fernald data, four GeoProbe locations were identified as issues, since for those four locations there have been only two sampling events, and those sampling events were separated by approximately four years. These four locations were dropped from the analysis. They were locations 13268, 12194, 13236, and 13237.

In the third step, GTS selects a temporal interpolation scheme for each well's time series as well as a temporal bandwidth to be applied to the data to support interpolation. Depending on the amount of data and its behavior, GTS chooses either a non-linear locally-weighted quadratic regression, a non-parametric linear trend method, or a flat line (for situations where all data are identical or non-detects). If there are not enough data to support a temporal interpolation for any particular well, GTS flags that well as having insufficient data. The user does not have the ability to over-ride GTS's selection of the temporal interpolation method, but can modify GTS's temporal bandwidth recommendation for any particular well. GTS supports bandwidths ranging from 0.4 to 0.8. In general, lower bandwidths provide less smoothing and allow the interpolation to better match high and low values present in a particular well's historical data. However low bandwidth numbers can result in large fluctuations in interpolated trends when there are temporal data gaps present (as an example, see Figure 12). Larger bandwidths provide for more smoothing and, in general, better match longer term average trends but may not accurately reflect observed data that deviate significantly from historical trends. GTS automatically selects a bandwidth for each well that can be manually overridden by the user. GTS does not provide guidance on selecting an appropriate bandwidth, other than to note that at times the GTS suggested bandwidth needs to be overridden.

For the purposes of this evaluation, GTS's default bandwidth values were used. For each well, GTS uses the selected interpolation method along with well-specific bandwidths to estimate a temporal trend line that includes confidence limits. For each trend line produced, GTS also calculates and displays a confidence interval around the trend line (as an example, see Figure 13). The trend line and associated confidence interval are important for temporal sampling frequency optimization when iterative thinning is used. At this stage of the analysis, GTS also provides maps color-coding monitoring locations by whether they exhibit increasing or decreasing concentration trends based on historical information (see Figure 14).

For the spatial baseline, the default GTS mesh of 100 grid nodes was retained. Spatial bandwidths were generated; for the purposes of this evaluation the bandwidth recommended by GTS for each time slice was retained. Spatial bandwidth behavior is similar to that for temporal bandwidths – small bandwidths allow better matching of data that deviate from averages at specific locations, but potentially introduce artifacts for areas where monitoring data are sparse while larger bandwidths improve the overall stability of spatial interpolations but will not model individual location deviations from the mean as well as low bandwidths.

Based on spatial bandwidth data and using its own spatial interpolation methodology, GTS constructs an interpolated concentration map for each time slice and compares the resulting map with the original data. Figure 15 shows this for one of the time slices; in this figure, monitoring locations are color-coded by whether the GTS interpolation under or overestimated the original data. This map would change if different spatial bandwidths were selected. At this point GTS can also display water table and concentration maps (as examples, see Figures 16 and 17).




| | Well Name | COC | Trend Type | Default Bandwidth | Selected Bandwidth |
|---|---|---|---|---|---|
| 1 | 12369-C | Uranium | LWQR | 0.4500 | 0.4500 |
| 2 | 12370-C | Uranium | LWQR | 0.4500 | 0.4500 |
| 3 | 12373-C | Uranium | LWQR | 0.5000 | 0.5000 |
| 4 | 2002 | Uranium | LWQR | 0.4500 | 0.4500 |
| 5 | 2014 | Uranium | LWQR | 0.5000 | 0.5000 |
| 6 | 2016 | Uranium | LWQR | 0.5500 | 0.5500 |
| 7 | 2017 | Uranium | LWQR | 0.5500 | 0.5500 |
| 8 | 2045 | Uranium | LWQR | 0.4500 | 0.4500 |
| 9 | 2046 | Uranium | LWQR | 0.5000 | 0.5000 |
| 10 | 2048 | Uranium | LWQR | 0.6500 | 0.6500 |
| 11 | 2049 | Uranium | LWQR | 0.5000 | 0.5000 |

Figure 12 Example of Bandwidth Effects

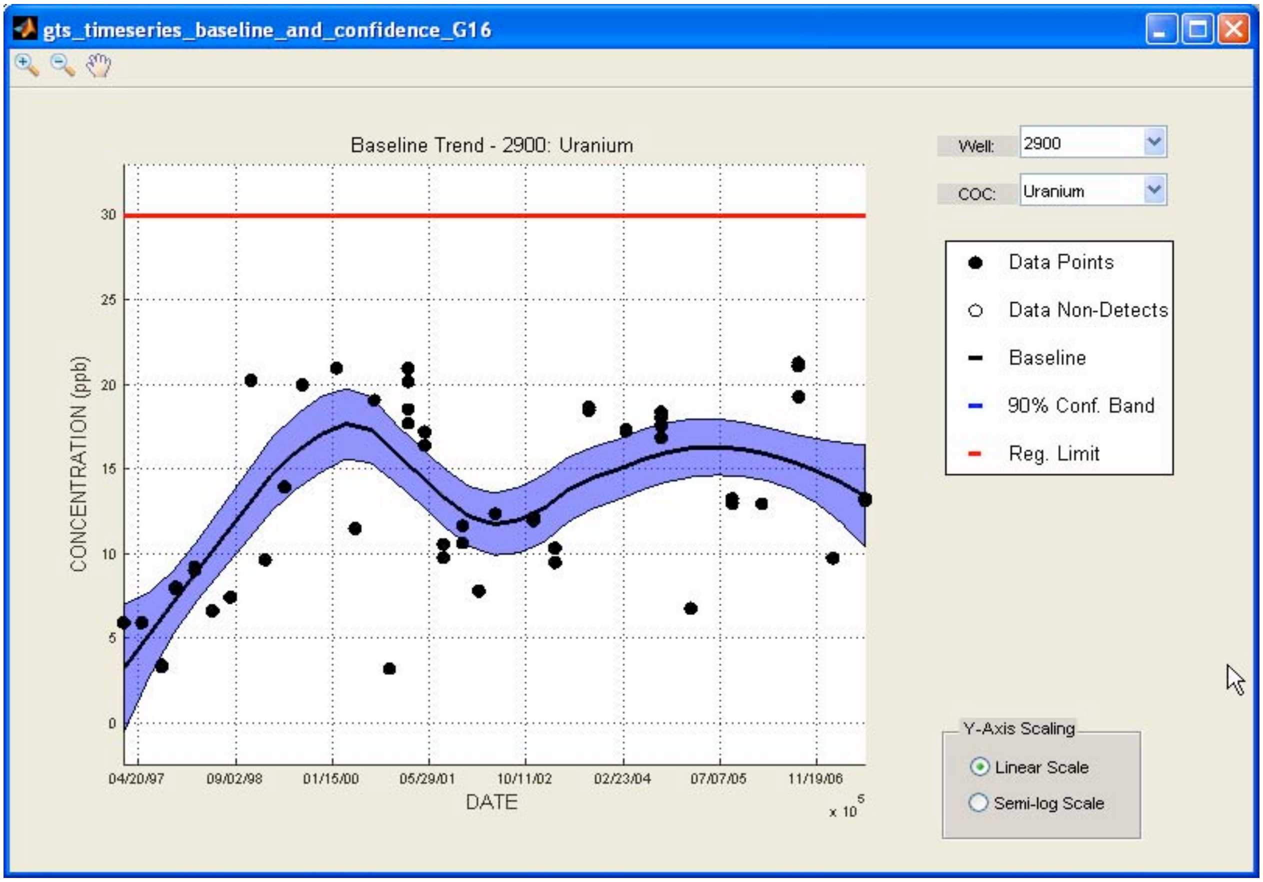



Figure 13 Baseline Temporal Trend Example with Confidence Intervals

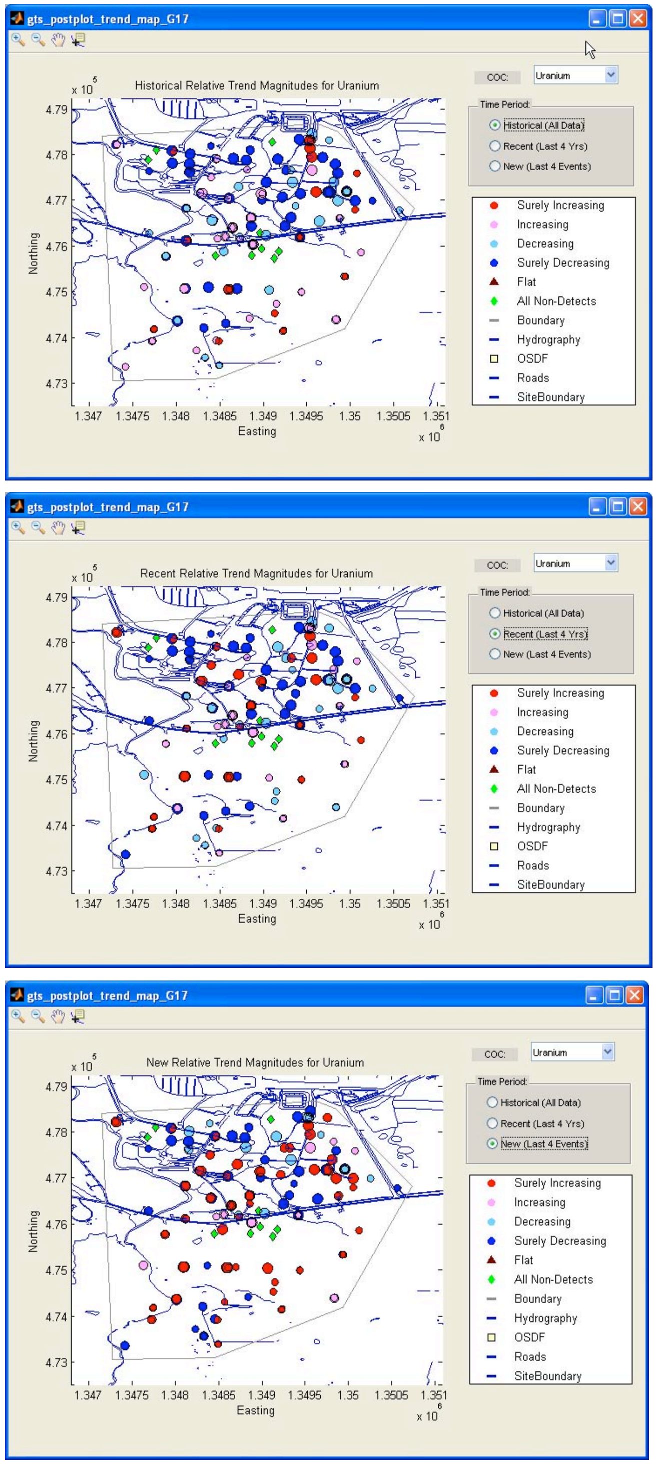
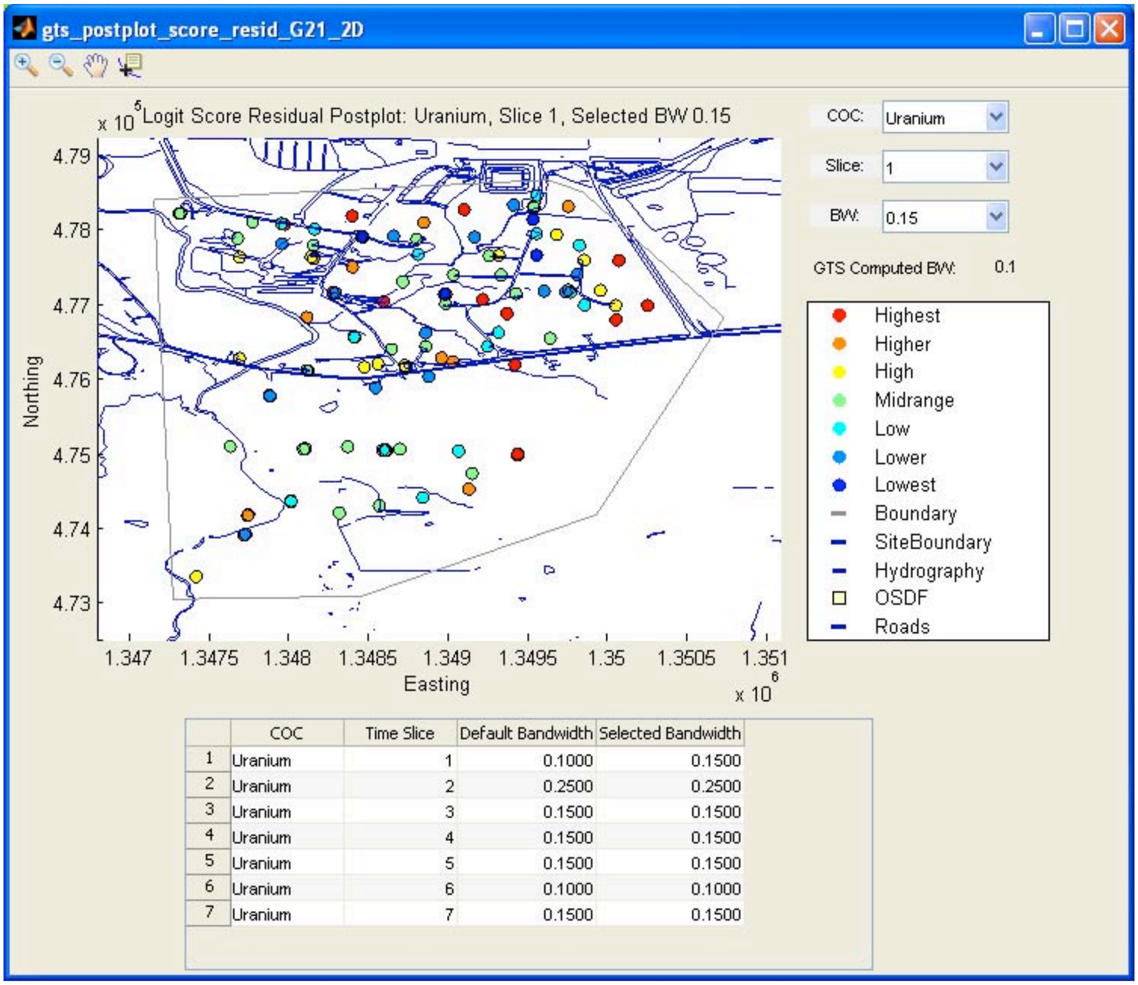



Figure 14 Recent Trend Maps for Fernald GTS Example




| | COC | Time Slice | Default Bandwidth | Selected Bandwidth |
|---|---|---|---|---|
| 1 | Uranium | 1 | 0.1000 | 0.1500 |
| 2 | Uranium | 2 | 0.2500 | 0.2500 |
| 3 | Uranium | 3 | 0.1500 | 0.1500 |
| 4 | Uranium | 4 | 0.1500 | 0.1500 |
| 5 | Uranium | 5 | 0.1500 | 0.1500 |
| 6 | Uranium | 6 | 0.1000 | 0.1000 |
| 7 | Uranium | 7 | 0.1500 | 0.1500 |

Figure 15 Logit Score Residual Post Plot for Fernald Example

## 6.4 GTS Optimize

GTS monitoring optimization is divided into two separate steps: optimizing temporal sampling frequency, and optimizing the spatial distribution of monitoring points.

GTS has two methods for addressing temporal sampling frequency. The first makes use of temporal variograms. The second uses iterative thinning techniques and the baseline temporal trends computed in the previous module. The temporal variogram produces a variogram for grouped set of wells – in the case of the Fernald data set, all wells within the area of interest. Variograms measure the degree of autocorrelation present in data sets as a function of some parameter – in the case of GTS that parameter is time. If a variogram reaches a plateau, or “sill”, the time to reach that sill indicates the time period required before sampling events show no correlation. This, in turn, can be used to select an appropriate sampling interval. In the case of the Fernald data set, no sill was apparent (Figure 18), a result consistent with the fact that uranium concentrations have been gradually falling across the site over time. Whenever consistent temporal trends are present, one would not expect variogram sills to be evident.

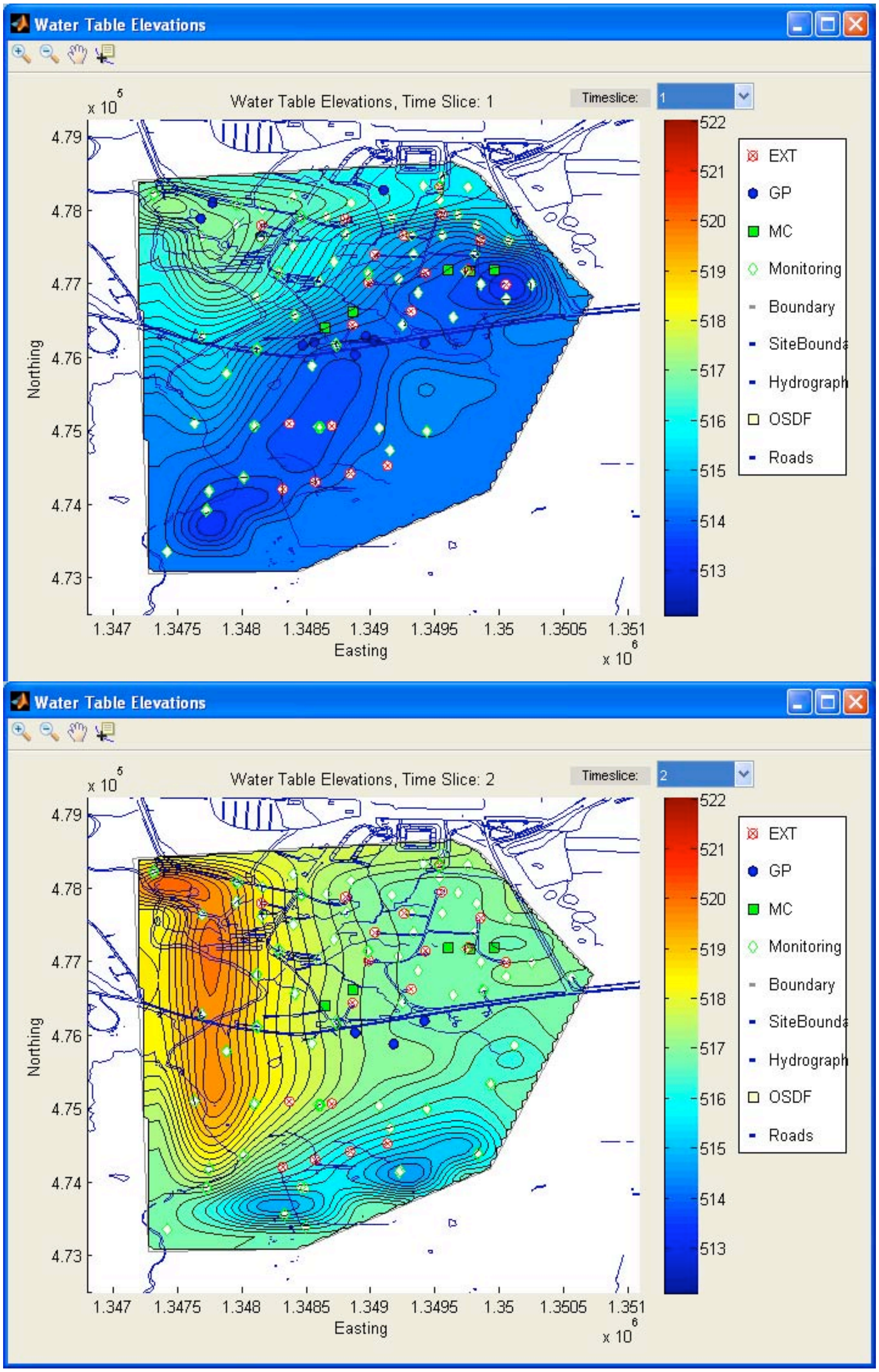



Figure 16 Water Table for Two Consecutive Time Slices

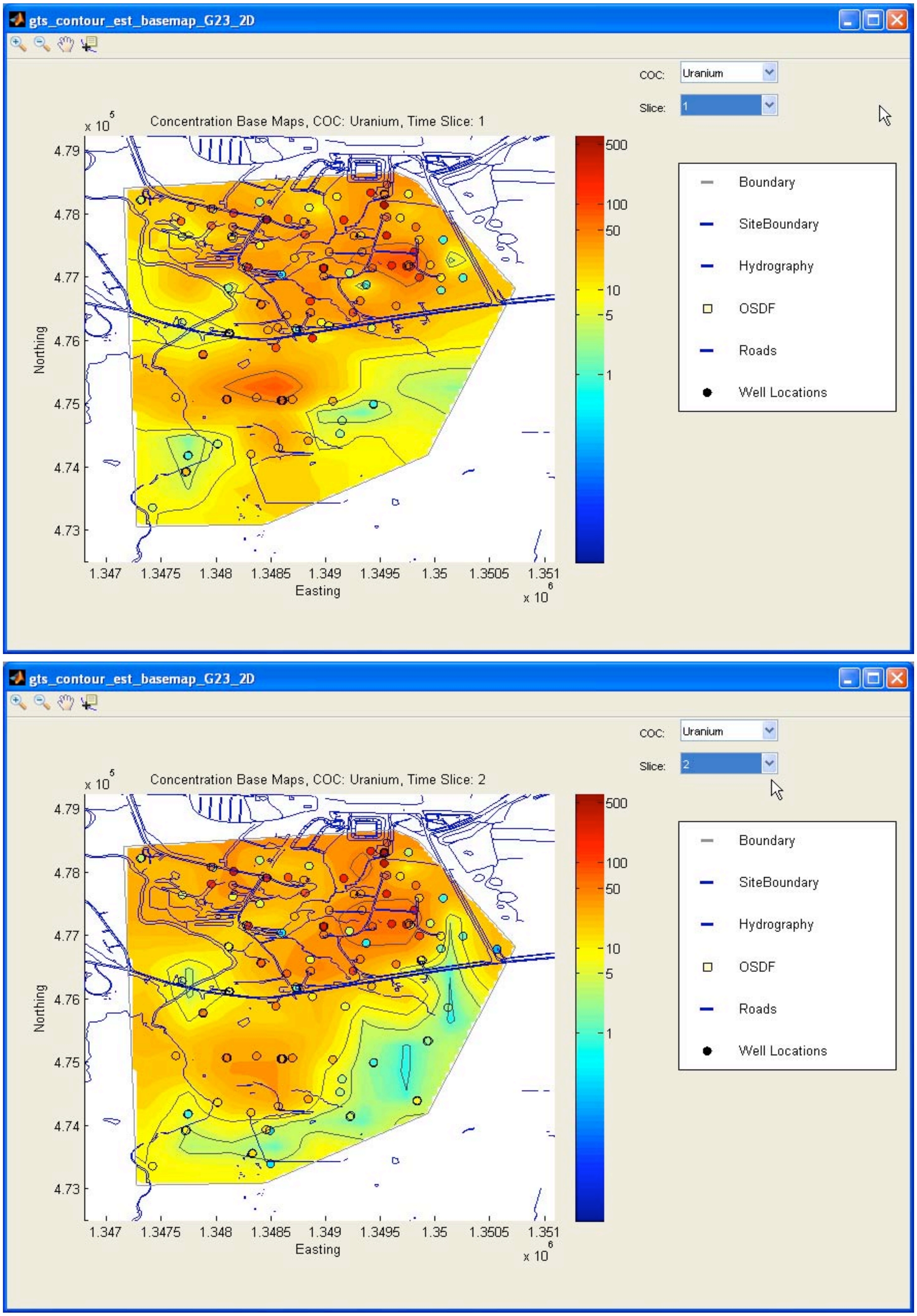



Figure 17 Uranium Concentrations for Two Consecutive Time Slices

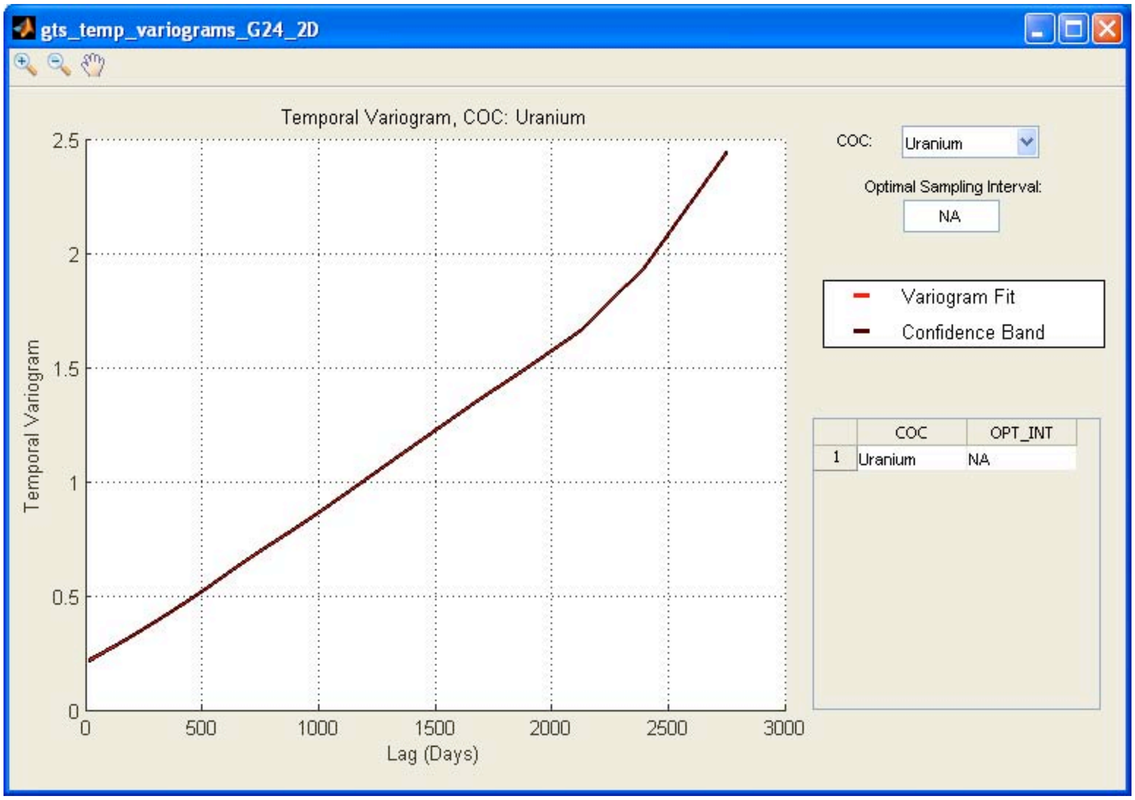



Figure 18 Generalized Temporal Variogram for Fernald Example

The second method makes use of iterative thinning to determine "optimal" sampling frequencies. Iterative thinning works on individual wells by selectively "dropping" historical data points, recalculating the apparent trend line with the remaining data, and comparing the recomputed trend with the original baseline trend for that well. Data point dropping continues until there is no longer good agreement between the recomputed trend and the original baseline trend. Iterative thinning is clearly very sensitive to the quality of the original baseline trend and the robustness of the trending method; any interpolation artifacts present in the original baseline trend or introduced when re-computing the trend can significantly affect the quality of the analysis.

Figure 19 shows the results of applying iterative thinning to the Fernald 2D problem. The histogram presents a summary of recommended sampling intervals across the example monitoring well with the median and the quartiles identified. The current base sampling frequency is twice a year for the majority of wells. The "optimal" quartile range identified by GTS ranged from 260 to 579 days, with a median of 447 days, or just over a year's spacing between sampling events. Because of replicable seasonal effects on uranium concentrations in many of the wells (presumably because of seasonal water table and flow fluctuations) it is important for data comparability over time that sampling for particular wells be done in the same season year to year; consequently the overall recommendation would that monitoring could be reduced to a yearly sampling program.

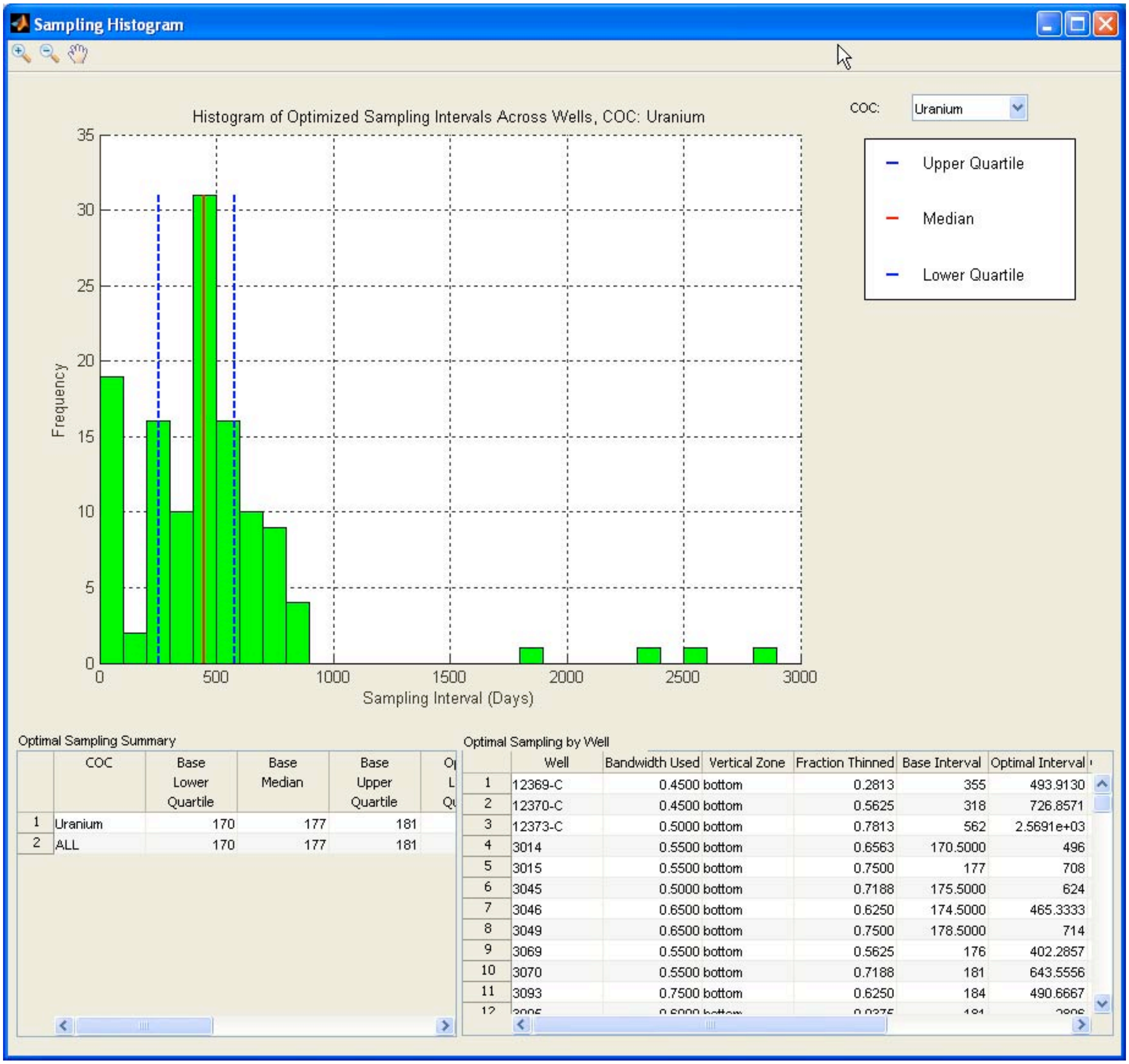


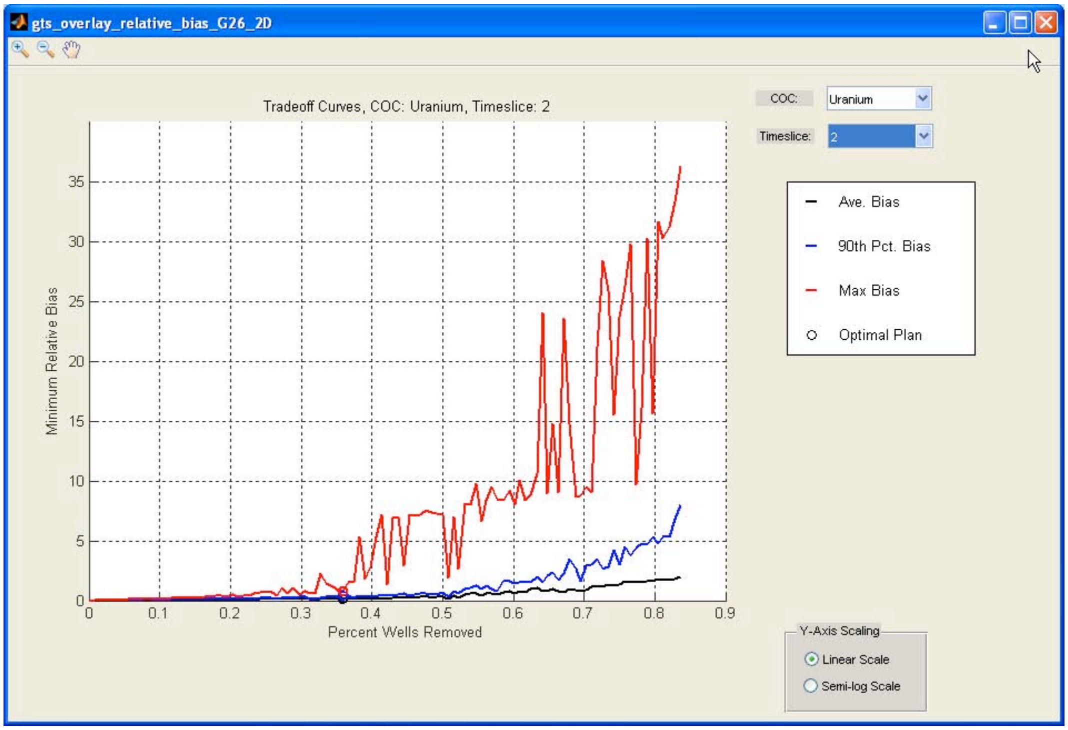

Figure 19 Summary of Iterative Thinning Results

The next step in the GTS analysis is to determine whether there is spatial redundancy in the monitoring network. GTS's algorithm compares interpolated concentration maps with wells deleted with the original baseline map. One would expect that as the number of wells deleted grows, the comparison would gradually deteriorate until at some point it would be deemed unacceptable. The redundancy analysis was performed on the 2D Fernald data set. Figure 20 shows graphs that indicate the degree of deviation from the baseline for the most recent two sampling rounds. GTS automatically selected the break-point where it believes the degree of

deviation is no longer acceptable. In the case of these two sampling rounds, the GTS results suggest that approximately 35% could be removed without too adversely affecting the ability to "correctly" interpolate the spatial location of groundwater contamination.

GTS provides maps and reports identifying which wells are redundant. Figure 21 shows the results of the 2D analysis – note that all extraction wells were marked as "protected" since they are sampled monthly as part of remedial system performance monitoring. There were 172 unique combinations of locations/vertical monitoring intervals representing 130 unique locations. Of the 172 unique combinations of locations/vertical monitoring intervals, GTS identified 31 as redundant. Figure 22 compares the interpolated base concentration map with the map that would have been obtained from the reduced set of monitoring wells with the redundant wells removed.

GTS also allows for an evaluation of spatial "data gaps" where an additional monitoring point might be warranted. Performing this analysis in 2D for the Fernald data set did not identify any spatial data gaps.



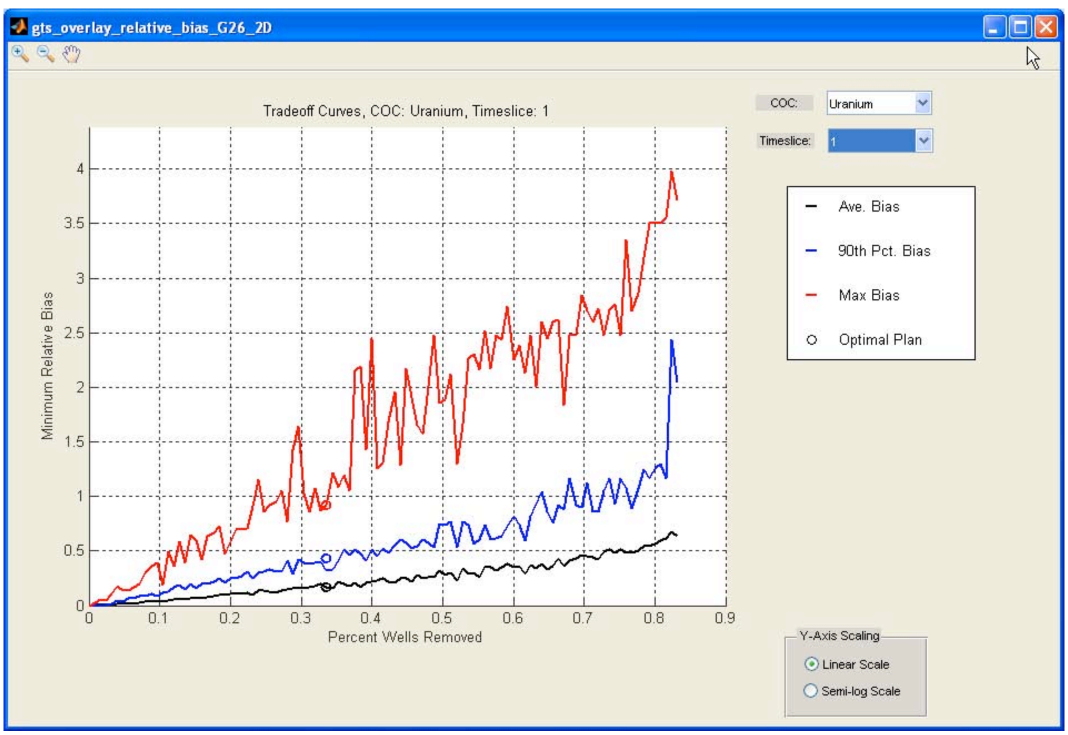




Figure 20 Spatial Redundancy Analysis Results

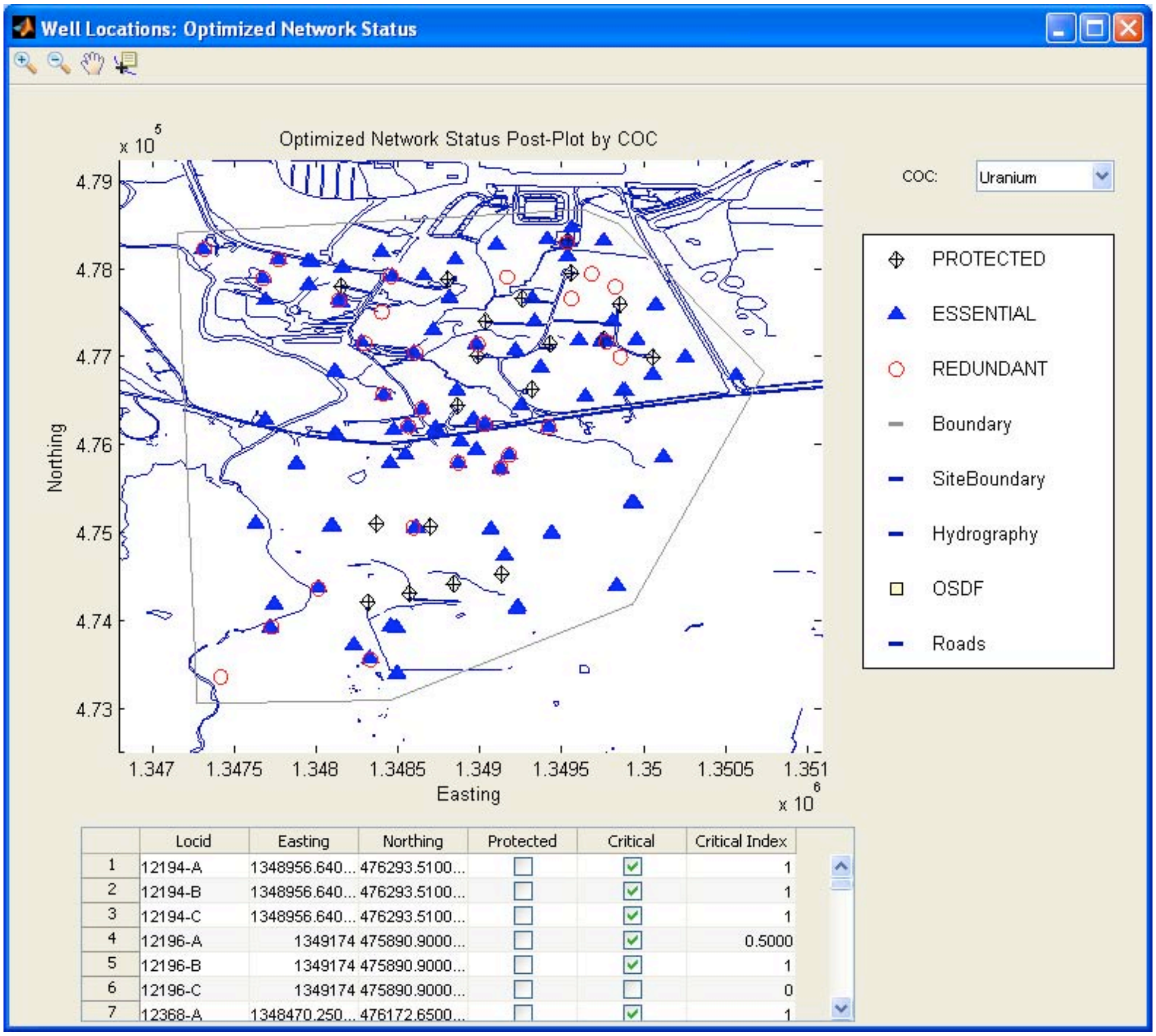



Figure 21 Map of Spatial Redundancy Analysis Results

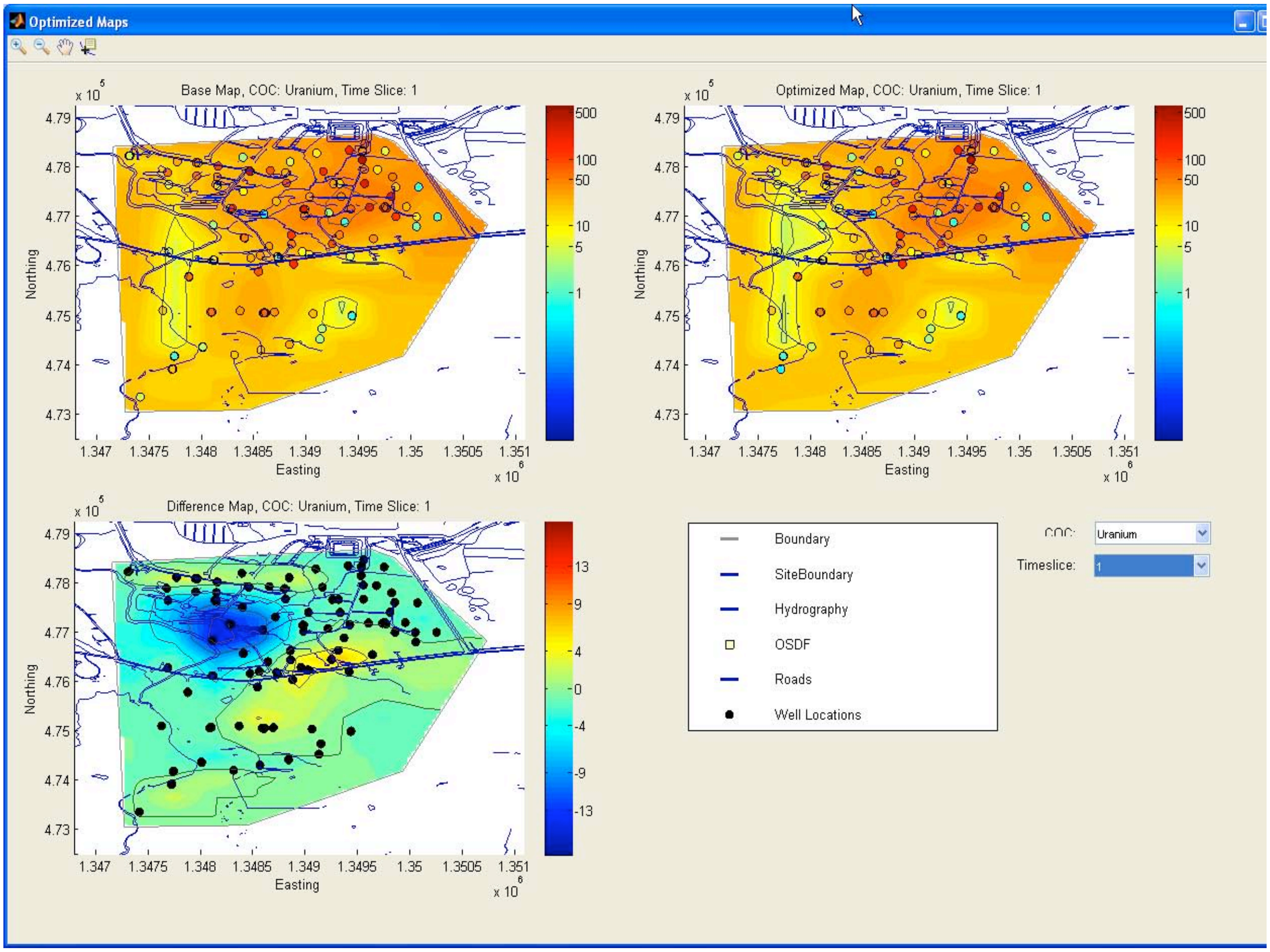



Figure 22 Concentration Map for Base Case and Reduced Network

## 7.0 Sensitivity Analysis

There are several major settings within GTS that potentially affect GTS recommendations. This sensitivity analysis focuses on three. The first of these is the temporal bandwidth selection. Temporal bandwidth selection potential affects the selection of an optimal sampling frequency for the site, but does not affect the spatial redundancy analysis. The base run of GTS described in the previous section used the GTS-selected bandwidth settings for individual wells. As an alternative, temporal bandwidths for every well were set to the maximum and the minimum GTS allows and the iterative thinning process re-run.

Of the 172 unique combinations of monitoring well location/vertical depth interval, GTS identified 121 as having sufficient data to support a temporal sampling frequency analysis. The average temporal bandwidth selected by GTS for these 121 wells was 0.58; the median recommended was 0.55. GTS allows bandwidths for individual wells to be set from 0.4 to 0.8. GTS temporal iterative thinning was run with all wells set to a bandwidth of 0.4, with bandwidths set to GTS-selected values, and with bandwidths set to 0.8.

The average base interval for Fernald wells was approximately 180 days; most Fernald wells are sampled bi-annually. The average optimal interval identified by GTS ranged from approximately 430 days (GTS-selected bandwidths) to 460 days (all bandwidths set to 0.4). Although there was little variation in the average optimal sampling interval identified by GTS when temporal bandwidths were varied, there were significant variations for individual wells. For example, if one focused strictly on the wells that were sampled bi-annually, the percent different between recommended optimal sampling frequencies for bandwidths equal to 0.4 and 0.8 ranged from -80% to 80%, with an average of 11%, indicating that while a 0.4 bandwidth on average resulted in a longer recommended time lag between sampling events, this was not always the case.

Figure 23 shows the GTS-optimized sampling frequency when the temporal bandwidth was set to 0.4 as a function of the initial base sampling frequency. As is apparent in this graph, the GTS-optimized temporal frequency is at least partially a function of the initial sampling frequency. However, as the cluster of points around a base interval of 180 days indicates, other factors influence optimal bandwidths as well. Based on a visual inspection of time series plots for these wells, in general GTS leans towards longer times between sampling events when historical data show a strong linear trend (either flat-line or linear increases or decreases). GTS leans towards shorter sampling intervals when historical data show non-linear trends, in particular sinusoidal types of movement in concentrations. GTS's selection of optimal sampling frequencies showed no correlation with average concentration (Figure 24).

The second is the spatial bandwidth selected. GTS selects default spatial bandwidth settings for each time slice analyzed; the user has the option of changing these spatial bandwidth settings for each time slice. Spatial bandwidth does not affect temporal sampling frequency, but does potentially affect the spatial redundancy analysis. The sensitivity analysis compared the effects of selecting the smallest spatial bandwidth on redundancy results with selecting the largest spatial bandwidth and with the GTS-selected bandwidth.

With the smallest spatial bandwidth selected, GTS identified 35 wells as redundant, not a significantly different number than for the base case when GTS self-selected well-specific bandwidths. However of these 35, only five were in common with the 31 wells GTS had selected for the base case. With the largest spatial bandwidth selected, GTS identified 84 wells as redundant; of these 84 eighteen were in common with the 31 wells selected as the base case. Clearly the selection of spatial bandwidths can have a significant impact on GTS results when evaluating monitoring well redundancy.

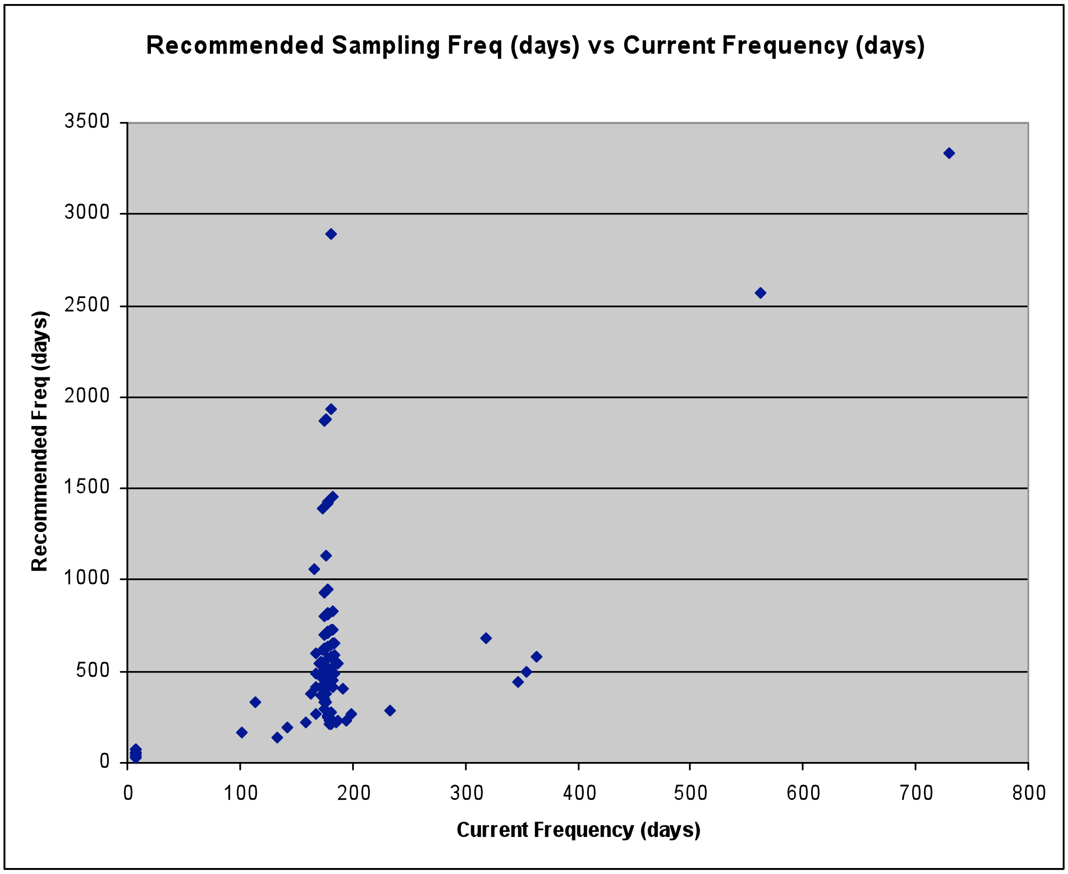



Figure 23 Optimal Frequency versus Base Frequency

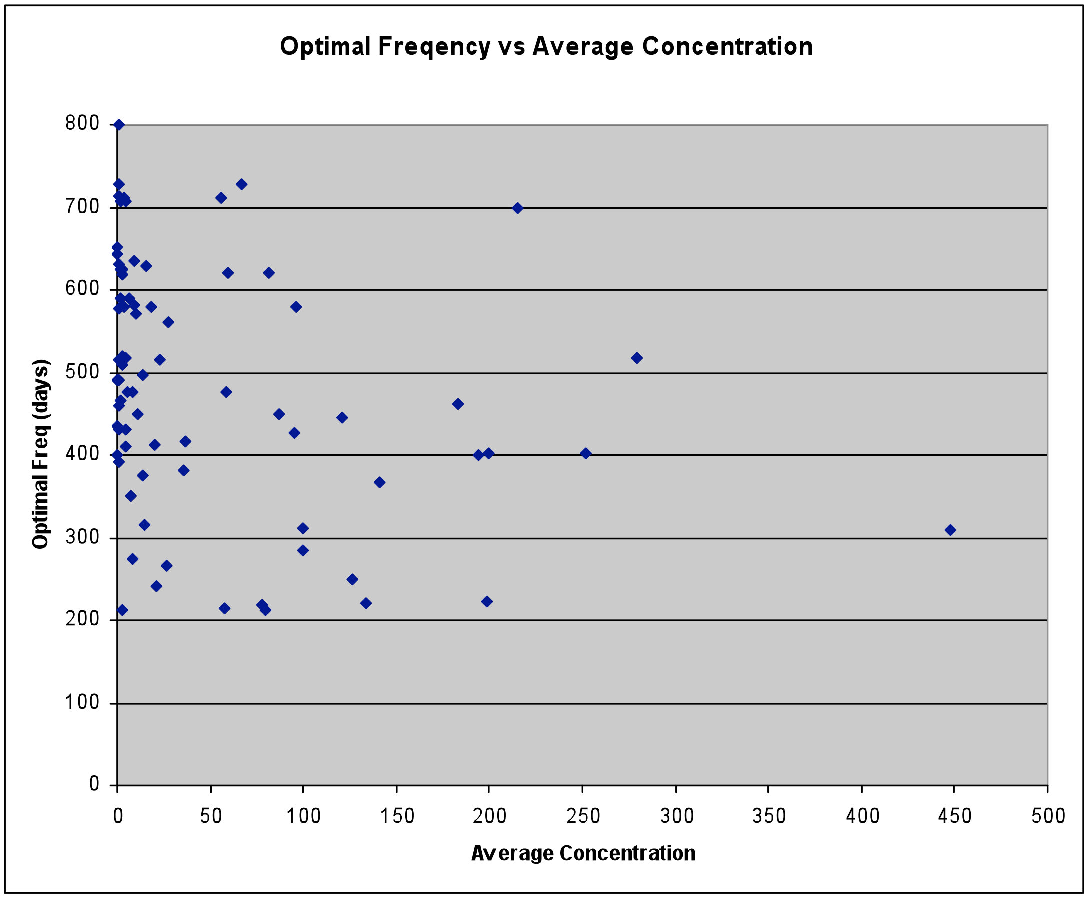



Figure 24 Optimal Frequency versus Average Concentration

The third is the choice between running a 2D analysis and a 2.5D analysis. The Fernald data set supported a 2.5D analysis since individual monitoring wells were screened in such a way as to target specific depth intervals. The three primary depth intervals of interest for the Fernald data are the water table, the middle of the upper Great Miami Aquifer, and the bottom of the upper Great Miami Aquifer. Selecting 2D versus 2.5D does not affect temporal sampling frequency, but does potentially affect the spatial redundancy analysis and the analysis of whether there are any spatial data gaps present that warrant additional monitoring wells.

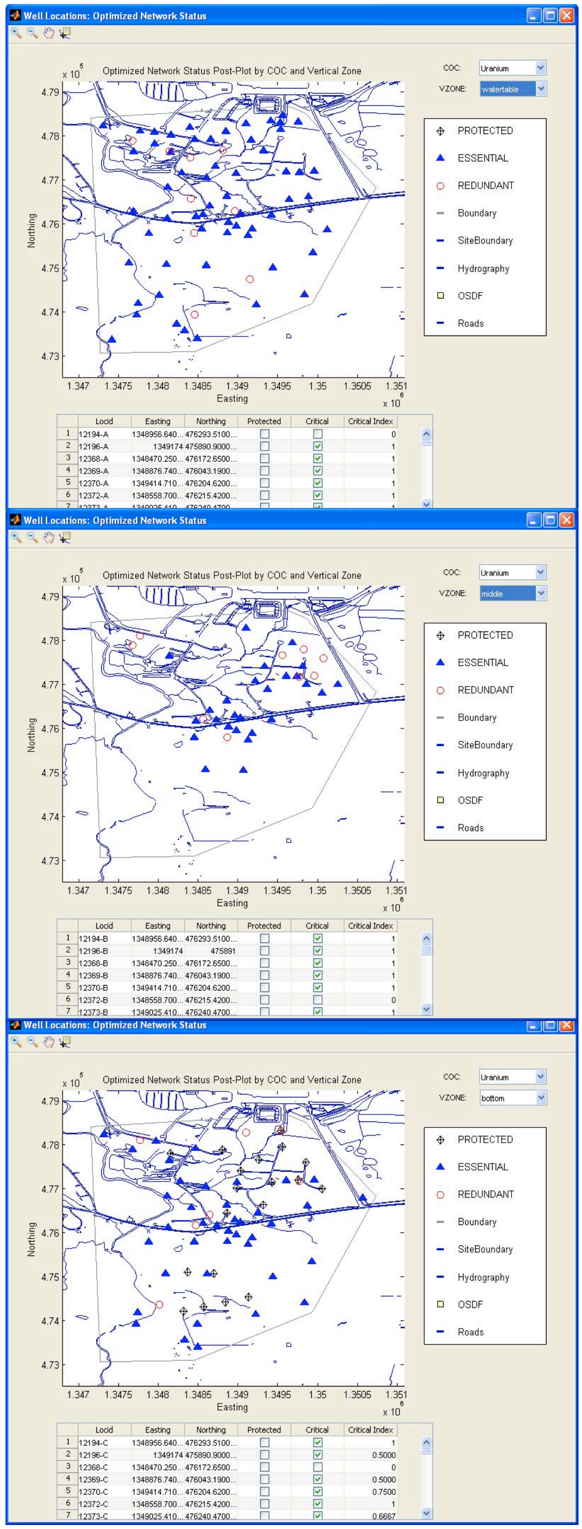



Figure 25 Spatial Redundancy Results for 2.5D Case

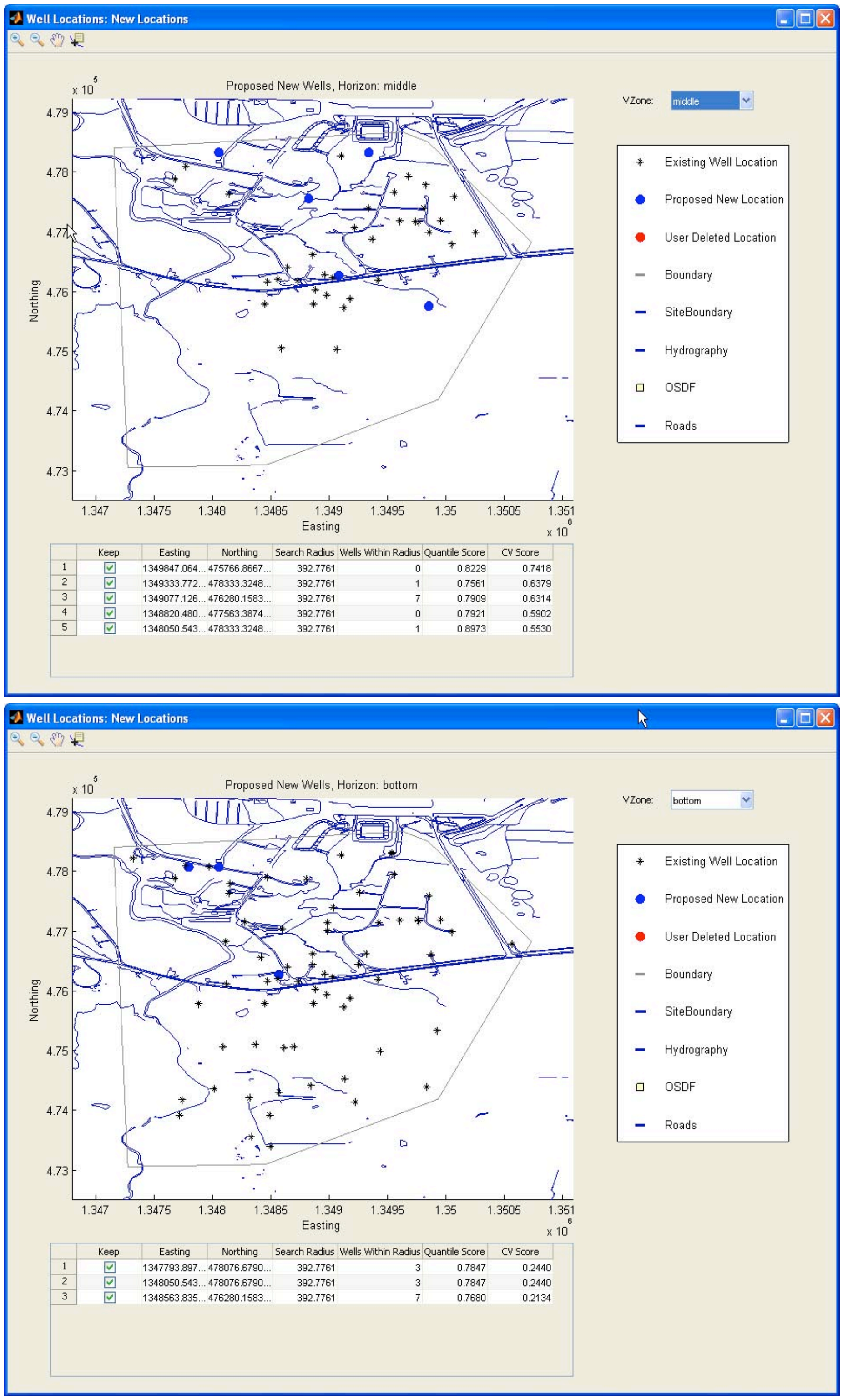



Figure 26 New Well Recommendations for 2.5D Case

The 172 unique location/vertical monitoring interval combinations include 69 allocated to the water table, 36 allocated to the middle of the upper Great Miami Aquifer, and 67 allocated to the bottom of the Great Miami Aquifer. All of the protected extraction wells were part of the last category. The spatial redundancy analysis identified 25 wells in all as being redundant across these three monitoring zones (as compared to 31 wells identified by the 2D analysis): nine from the water-table group, nine from the middle group, and seven from the bottom group. Figure 25 shows the locations of these wells; note that while the number of redundant wells identified by the 2.5D analysis was not that much different from the 2D analysis, the specific wells selected as redundant were very different from the 2D analysis – only ten wells were identified by both the 2D and 2.5D analyses as redundant.

Unlike the 2D spatial data gap analysis, the 2.5D spatial data gap analysis identified spatial data gaps for two of the three monitored vertical zones, the middle (three new wells) and the bottom (five wells). Figure 26 shows the locations of the proposed new wells; many of these locations were proximal to existing wells. The overall conclusion is that a 2D versus 2.5D analysis with the same data sets can produce significantly different results using GTS.

## 8.0 Discussion and Conclusions

The purpose of applying GTS to the Fernald groundwater monitoring program was to provide an overall evaluation of GTS functionality, and to determine whether GTS could suggest modifications to the current monitoring regime that would reduce costs without compromising monitoring system performance, either by increasing the time between sampling events and/or eliminating redundant monitoring wells.

GTS provides excellent data visualization tools; in particular its time series plots are invaluable for visually identifying non-detect values, outliers, and temporal trends.

The overall conclusion of GTS's iterative thinning algorithm was that for the south plume, the average length of time between samples could likely be extended well beyond the current bi-annual protocol without affecting monitoring system performance. The average temporal frequency recommended by GTS was more than a year; given the obvious seasonality effects present in the Fernald data set for many wells, the recommendation would be to increase the time between sampling events to one year, with care taken that individual wells be sampled at approximately the same time each year so that cross-year comparisons will not be unduly affected by seasonal variations that have been observed in the Fernald data. This is an average conclusion; well-specific sampling frequencies recommended by GTS varied widely.

The temporal bandwidth selection did have an impact on individual well recommendations, but did not appear to have a significant effect on overall recommendations (on average). The interpolation of temporal trends for wells with temporal data gaps was particularly sensitive to bandwidth selection (see Figure 12 for an example); the effect of this on individual well sampling frequencies was not explored, but one would expect the effect to be significant.

There was a correlation noted between base sampling frequency and the GTS-recommended frequency. The longer the base sampling frequency, the longer was the GTS-recommended sampling frequency. Ideally one would want the "optimal" sampling frequency to be independent of the original sampling frequency. Also there was no correlation between the GTS-recommended sampling frequency and the average concentration for a well. One might

expect that wells that are significantly and consistently elevated above a cleanup guidelines, or significantly and consistently below, might be of lesser interest from a sampling frequency perspective than wells that have concentrations around the action level.

The overall conclusion of GTS's spatial redundancy analysis was that the monitoring program could be reduced by approximately 18% based on the 2D analysis. However this conclusion appeared to be very sensitive to whether the analysis was conducted in 2D or 2.5D and to the spatial bandwidth selected. In addition, the wells identified as redundant did not always appear to make visual sense. Consequently the recommendation would be that a further evaluation of Fernald data be undertaken before implementing GTS's recommendations. The spatial data gap analysis also provided data on proposed new monitoring well locations; as with the redundancy analysis there was some question based on visual inspection as to the appropriateness of the recommended locations.

GTS provides a powerful tool for evaluating and potentially optimizing groundwater monitoring networks. Additional work should be done to validate the appropriateness and reasonableness of its spatial redundancy and spatial data gaps analyses. Because of the complexity of the temporal and spatial optimization analyses it performs, GTS is best used by environmental professionals who have a solid understanding of subsurface fate and transport phenomena and at least some background in statistical analyses.

## FERNALD OPTIMIZATION RESULTS COMPUTED BY ESTCP PROJECT TEAM

# GTS Optimized Network Status Report

### Summary of Optimized Status for Each Well as Identified by GTS using the NPL Dataset

Project = fernald_100217
AFIID/Site = FERNALD/FS
Date Completed = August 5, 2010
Author = MacStat Consulting, Ltd/Kirk Cameron

### Using Iterative Thinning

| GTS Well ID | Loc ID | Well Type | Easting | Northing | Sample Elevation | Vertical Zone | Protected Status | Critical Status | Critical Index | Baseline Frequency (per year) | Baseline Interval (days) | Well-Specific Optimal Frequency (per year) | Well-Specific Optimal Interval (days) | Zone-Based Optimal Frequency (per year) | Zone-Based Optimal Interval (days) | Site-Based Optimal Frequency (per year) | Site Bas Opti Inter (day |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 1027 | MW | 1347850.48 | 482010.18 | 560.885 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 65 | 1Q (4) | 72 | NA | NA | 3Q (1.33) | 239 |
| 4 | 1031 | MW | 1346667.6 | 481196.45 | 556.335 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 8 | 1042 | MW | 1348074.28 | 480418.15 | 562.285 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 19 | 12192 | GP | 1349254.05 | 476518.15 | 517.1 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 20 | 12194 | GP | 1348956.64 | 476293.51 | 513.8 | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 21 | 12196 | GP | 1349174 | 475890.95 | 514.5525 | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 24 | 12230 | GP | 1348629.59 | 476757.865 | 513.41 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 25 | 12231 | GP | 1348790.615 | 476554.235 | 521.435 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 26 | 12232 | GP | 1349144.665 | 476799.26 | 518.395 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 29 | 12235 | GP | 1348785.587 | 475062.9067 | 517.866667 | ONE_LAYER | No | Yes | 1 | 4Q (1) | 374 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 31 | 12237 | GP | 1348014.66 | 475280.645 | 520.14 | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 35 | 12367 | GP | 1347991.034 | 476145.3938 | 513.435 | ONE_LAYER | No | No | 0 | 3Q (1.3333) | 275 | 7Q (0.57) | 620 | NA | NA | 3Q (1.33) | 239 |
| 36 | 12368 | GP | 1348469.657 | 476170.3478 | 510.472222 | ONE_LAYER | No | Yes | 0.6667 | 3Q (1.3333) | 313 | 5Q (0.8) | 484 | NA | NA | 3Q (1.33) | 239 |
| 37 | 12369 | GP | 1348855 | 476073.4 | 505.7706 | ONE_LAYER | No | No | 0.3333 | 1Q (4) | 4 | 3Q (1.33) | 251 | NA | NA | 3Q (1.33) | 239 |
| 38 | 12370 | GP | 1349398.583 | 476223.3125 | 506.64875 | ONE_LAYER | No | No | 0.3333 | 1Q (4) | 2 | 7Q (0.57) | 628 | NA | NA | 3Q (1.33) | 239 |
| 39 | 12371 | GP | 1350065.288 | 476407.9367 | 514.475714 | ONE_LAYER | No | Yes | 1 | 2Q (2) | 136 | 7Q (0.57) | 626 | NA | NA | 3Q (1.33) | 239 |
| 40 | 12372 | GP | 1348561 | 476215 | 513.5087 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 3.5 | 2Q (2) | 164 | NA | NA | 3Q (1.33) | 239 |
| 41 | 12373 | GP | 1349039 | 476214.6 | 508.63055 | ONE_LAYER | No | No | 0.3333 | 1Q (4) | 4 | 2Q (2) | 183 | NA | NA | 3Q (1.33) | 239 |
| 43 | 12406 | GP | 1349707.68 | 478870.07 | | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 44 | 12407 | GP | 1349891.09 | 478218.07 | | ONE_LAYER | No | Yes | 1 | 1Q (4) | 4 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 45 | 12408 | GP | 1349833.05 | 477806.19 | | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 46 | 12409 | GP | 1349347.26 | 477184.56 | | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 47 | 12410 | GP | 1348899.4 | 476733.17 | | ONE_LAYER | No | No | 0 | 1Q (4) | 5 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 48 | 12411 | GP | 1348465.06 | 476846.26 | 518.09 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 2 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 49 | 12415 | GP | 1349212.86 | 478307.11 | | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 50 | 12416 | GP | 1349526.61 | 476809.3 | 516.55 | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 52 | 12431 | GP | 1350130.49 | 477650.12 | | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 53 | 12432 | GP | 1350086.92 | 477851.93 | | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 54 | 12433 | GP | 1349747.26 | 477184.56 | | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 55 | 12434 | GP | 1350280.79 | 477184.56 | | ONE_LAYER | No | No | 0 | 1Q (4) | 4 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 56 | 12442 | GP | 1349789.92 | 477505.83 | | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 57 | 12443 | GP | 1349813.27 | 476903.74 | | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 63 | 12614 | GP | 1347182.52 | 481895.005 | 535.33 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 5 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 64 | 12615 | GP | 1347540.03 | 482028.18 | 521.41 | ONE_LAYER | No | Yes | 0.5 | 10Q (0.4) | 925 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 65 | 12616 | GP | 1347585.36 | 481556.17 | | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 66 | 12617 | GP | 1347225.195 | 481285.395 | 569.99 | ONE_LAYER | No | No | 0 | 1Q (4) | 5 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 67 | 12618 | GP | 1347201.15 | 480422.4 | 516.445 | ONE_LAYER | No | No | 0 | 10Q (0.4) | 892 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 68 | 12619 | GP | 1346549.31 | 479572.76 | | ONE_LAYER | No | Yes | 1 | 1Q (4) | 2.5 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 69 | 12651 | GP | 1350074.26 | 480063.67 | | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 70 | 12652 | GP | 1350392.32 | 479978.09 | | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 71 | 12653 | GP | 1350322.73 | 480229.92 | | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 72 | 12684 | GP | 1347143.335 | 480922.99 | 516.76 | ONE_LAYER | No | Yes | 0.5 | 10Q (0.4) | 858 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 73 | 12686 | GP | 1347700 | 480655 | | ONE_LAYER | No | Yes | 1 | 1Q (4) | 5 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 76 | 12707 | GP | 1346826.44 | 479978.25 | | ONE_LAYER | No | No | 0 | 1Q (4) | 2.5 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 77 | 12708 | GP | 1347228.79 | 479929.42 | | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 78 | 12709 | GP | 1348970.15 | 482536.36 | | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 79 | 12710 | GP | 1347698.84 | 479905.945 | | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 80 | 12711 | GP | 1348047.495 | 479852.79 | | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 81 | 12712 | GP | 1347188.23 | 479651.97 | | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 82 | 12713 | GP | 1347469.99 | 480205.1 | | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 83 | 12714 | GP | 1348074.61 | 482113.66 | | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 84 | 12715 | GP | 1348375.99 | 479899.17 | | ONE_LAYER | No | No | 0 | 1Q (4) | 1.5 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 85 | 12716 | GP | 1347820.94 | 479494.85 | | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 86 | 12717 | GP | 1348139.79 | 480201.47 | | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 87 | 12718 | GP | 1348752.07 | 479679.09 | | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 88 | 12719 | GP | 1348408.53 | 481478.14 | | ONE_LAYER | No | Yes | 1 | 1Q (4) | 2 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 89 | 12720 | GP | 1348375.3 | 479461.66 | | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 90 | 12721 | GP | 1348748.82 | 479987.06 | | ONE_LAYER | No | No | 0 | 1Q (4) | 2 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 91 | 12722 | GP | 1346486.51 | 479902.81 | | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 92 | 12723 | GP | 1349265.1 | 480079.65 | | ONE_LAYER | No | No | 0 | 1Q (4) | 2 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 93 | 12724 | GP | 1348750.03 | 480362.18 | | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 94 | 12725 | GP | 1348148.23 | 480390.06 | | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 95 | 12814 | GP | 1347673.705 | 477898.55 | | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 96 | 12815 | GP | 1347647.85 | 478086.42 | | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 97 | 12816 | GP | 1347945.79 | 477721.21 | | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 98 | 12817 | GP | 1349724.51 | 478725.48 | | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 99 | 12818 | GP | 1348109.58 | 477099.26 | | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 100 | 12819 | GP | 1348986.75 | 478562.76 | | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 101 | 12820 | GP | 1349173.48 | 478798.46 | | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 102 | 12824 | GP | 1348039.19 | 477920.7 | | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 103 | 12825 | GP | 1347883.87 | 478236.33 | | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 104 | 12826 | GP | 1348116.51 | 477775.2 | | ONE_LAYER | No | Yes | 1 | 1Q (4) | 4 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 105 | 12827 | GP | 1348274.45 | 477920.32 | | ONE_LAYER | No | No | 0 | 1Q (4) | 4 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 106 | 12828 | GP | 1348328.27 | 477803.17 | | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 107 | 12829 | GP | 1350740.61 | 480053.23 | | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 108 | 12830 | GP | 1350739.01 | 480271.52 | | ONE_LAYER | No | No | 0 | 1Q (4) | 4 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 109 | 12831 | GP | 1350740.13 | 480479.1 | | ONE_LAYER | No | No | 0 | 1Q (4) | 5 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 110 | 12832 | GP | 1350594.19 | 480737.07 | | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 111 | 12833 | GP | 1349411.68 | 478335.75 | | ONE_LAYER | No | Yes | 1 | 1Q (4) | 4 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 112 | 12834 | GP | 1349531.55 | 478460.34 | | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 113 | 12835 | GP | 1349678.12 | 478280.9 | | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 114 | 12836 | GP | 1349497.37 | 478155.77 | | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 115 | 12837 | GP | 1348348.85 | 478025.74 | | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 116 | 12838 | GP | 1348129.11 | 478071.68 | | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 117 | 12839 | GP | 1348137.655 | 477647.925 | | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 118 | 12840 | GP | 1348447.03 | 477672.76 | | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 119 | 12841 | GP | 1347879.23 | 477609.96 | | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 120 | 12842 | GP | 1348644.25 | 477701.42 | | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 121 | 12843 | GP | 1349534.2 | 478320.2 | | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 122 | 12844 | GP | 1348862.32 | 478081.06 | 512.59 | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 123 | 12845 | GP | 1348802.74 | 477713.24 | 512.35 | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 124 | 12856 | GP | 1349276.49 | 480402.09 | | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 125 | 12857 | GP | 1349277.33 | 480621.33 | | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 126 | 12858 | GP | 1349105.82 | 479765.54 | | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 127 | 12859 | GP | 1351638.56 | 480778.39 | | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 128 | 13 | MW | 1349768.29 | 476286.38 | | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 97 | 2Q (2) | 224 | NA | NA | 3Q (1.33) | 239 |
| 129 | 13226 | GP | 1348202.75 | 475971.63 | 510.603333 | ONE_LAYER | No | Yes | 1 | 4Q (1) | 376 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 130 | 13227 | GP | 1348640.87 | 475878.91 | 513 | ONE_LAYER | No | No | 0 | 7Q (0.5714) | 634.5 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 131 | 13228 | GP | 1349166 | 476147.2 | 520.43 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 132 | 13229 | GP | 1348250.57 | 475547.925 | 517.1 | ONE_LAYER | No | No | 0 | 2Q (2) | 169 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 133 | 13230 | GP | 1348648.68 | 475599.055 | 515 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 2 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 134 | 13231 | GP | 1349046.11 | 475603.48 | 516.5 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 135 | 13232 | GP | 1348213 | 475179.3 | 499.5 | ONE_LAYER | No | No | 0 | 1Q (4) | 28 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 136 | 13233 | GP | 1348648.79 | 475197.93 | 513 | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 137 | 13234 | GP | 1349045.91 | 475201.39 | 469 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 138 | 13235 | GP | 1348047.84 | 475808.515 | 509.605 | ONE_LAYER | No | Yes | 0.5 | 9Q (0.4444) | 847.5 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 139 | 13236 | GP | 1348446.96 | 475799.02 | 511.575 | ONE_LAYER | No | Yes | 0.5 | 9Q (0.4444) | 854.5 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 140 | 13237 | GP | 1348854.005 | 475800.745 | 511.6925 | ONE_LAYER | No | Yes | 0.5 | 10Q (0.4) | 860.5 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 141 | 13238 | GP | 1348082.95 | 475396.39 | 515.9 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 142 | 13239 | GP | 1348446.43 | 475400.26 | 515 | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 143 | 13240 | GP | 1348846.523 | 475400.05 | 514.816667 | ONE_LAYER | No | Yes | 1 | 4Q (1) | 349 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 144 | 13241 | GP | 1350070.84 | 477048.77 | 515 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 145 | 13242 | GP | 1350057.58 | 480361.65 | 512.84 | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 146 | 13247 | GP | 1350286.6 | 476939.4 | 513.7 | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 147 | 13248 | GP | 1350096.7 | 477312.5 | 513.6 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 148 | 13256 | GP | 1349137.76 | 482174.5 | 512 | ONE_LAYER | No | No | 0 | 1Q (4) | 4 | NA | NA | NA | NA | 3Q (1.33) | 239 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 149 | 13267 | GP | 1348843 | 475193 | 516.63 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 150 | 13268 | GP | 1348974.92 | 475951.205 | 512.075 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 151 | 13269 | GP | 1349283.88 | 476018.26 | 518.4 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 152 | 13270 | GP | 1347997.59 | 475980.66 | 515 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 153 | 13297 | GP | 1349401 | 475889 | 513 | ONE_LAYER | No | No | 0 | 1Q (4) | 4 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 154 | 13300 | GP | 1348285.02 | 474905.58 | 514 | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 155 | 13301 | GP | 1348586.54 | 474907.61 | 513 | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 156 | 13302 | GP | 1348892.04 | 474903.59 | 515 | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 157 | 13303 | GP | 1348217.57 | 474728.95 | 514.5 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 2.5 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 158 | 13306 | GP | 1348309.18 | 474546.02 | 514.5 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 2.5 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 159 | 13307 | GP | 1348539.58 | 474495.1 | | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 160 | 13308 | GP | 1348969.4 | 474566.21 | 512 | ONE_LAYER | No | No | 0 | 1Q (4) | 2 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 161 | 13310 | GP | 1349074.82 | 474386.8 | 509.97 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 162 | 13311 | GP | 1350146 | 480909.5 | 515.2 | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 163 | 13312 | GP | 1350098 | 480953.3 | 516.24 | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 164 | 13314 | GP | 1350297 | 480505.8 | 515.89 | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 165 | 13315 | GP | 1350103 | 480371.6 | 516.13 | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 166 | 13316 | GP | 1350180 | 480370.4 | 517.57 | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 167 | 13317 | GP | 1349805 | 480174.3 | 519.1 | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 168 | 13318 | GP | 1349877 | 480171.9 | 515.48 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 169 | 13319 | GP | 1349176.56 | 476268.64 | 515.93 | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 170 | 13320 | GP | 1346841.02 | 481553.8 | 519.53 | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 171 | 13322 | GP | 1346680.03 | 481348.78 | 520.07 | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 172 | 13323 | GP | 1347859.56 | 481998.98 | 514.81 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 173 | 13324 | GP | 1346794 | 481088.3 | 518.9 | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 174 | 13325 | GP | 1347024 | 481088.03 | 518.65 | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 175 | 13327 | GP | 1346808.85 | 480802.6 | 520.42 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 176 | 13328 | GP | 1346653.46 | 481066.3 | 521.39 | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 177 | 13329 | GP | 1347306.47 | 480540.77 | 520.17 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 178 | 13342 | GP | 1348178 | 481495.2 | 514.38 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 179 | 13343 | GP | 1347668 | 481487.2 | 517.83 | ONE_LAYER | No | No | 0 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 180 | 13344 | GP | 1348415.92 | 481444.45 | 513.62 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 181 | 13345 | GP | 1348673.04 | 481434.18 | 515.95 | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 182 | 13355 | GP | 1348974.76 | 477353.95 | | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 183 | 13356 | GP | 1349685.76 | 476445.76 | 508.99 | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 184 | 13359 | GP | 1347883.04 | 475449.04 | 509.62 | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 185 | 14 | MW | 1352278.44 | 477200.58 | | ONE_LAYER | No | Yes | 1 | 1Q (4) | 97 | 3Q (1.33) | 265 | NA | NA | 3Q (1.33) | 239 |
| 187 | 1490 | MW | 1349040.12 | 478894.86 | 568.035 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 188 | 1564 | MW | 1348628.22 | 478381.45 | 563.355 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 194 | 1675 | MW | 1349591.6 | 481212.2 | 573.845 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 195 | 1676 | MW | 1349510.38 | 481216.91 | 573.555 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 196 | 1684 | MW | 1348852.72 | 478296.81 | 561.23 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 197 | 1685 | MW | 1348964.07 | 478527.82 | 563.725 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 198 | 1719 | MW | 1348230.14 | 482244.96 | 577.17 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 206 | 1800 | MW | 1348922.57 | 480254.41 | 576.73 | ONE_LAYER | No | No | 0 | 1Q (4) | 30.5 | 1Q (4) | 62 | NA | NA | 3Q (1.33) | 239 |
| 209 | 1934 | MW | 1348275.8 | 480423.45 | 564.715 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 212 | 1950 | MW | 1348080.64 | 482231.5 | 569.865 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 213 | 2002 | MW | 1349146.09 | 474748.31 | 515.85 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 98 | 4Q (1) | 345 | NA | NA | 3Q (1.33) | 239 |
| 215 | 2006 | MW | 1349094.67 | 480382.82 | 520.2 | ONE_LAYER | Yes | Yes | 1 | 15Q (0.2667) | 1335 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 216 | 2007 | MW | 1349169.53 | 480634.89 | 517.965 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 217 | 2008 | MW | 1347449.02 | 480690.79 | 515.345 | ONE_LAYER | No | Yes | 0.75 | 2Q (2) | 140 | 4Q (1) | 364 | NA | NA | 3Q (1.33) | 239 |
| 218 | 2009 | MW | 1346538.77 | 479570.06 | 521.775 | ONE_LAYER | No | Yes | 0.5 | 2Q (2) | 156.5 | 4Q (1) | 391 | NA | NA | 3Q (1.33) | 239 |
| 219 | 2010 | MW | 1348222.04 | 481489.91 | 517.91 | ONE_LAYER | No | No | 0 | 1Q (4) | 128.5 | 5Q (0.8) | 411 | NA | NA | 3Q (1.33) | 239 |
| 220 | 2011 | MW | 1346490.3 | 482300.99 | 452.8 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 221 | 2014 | MW | 1348115.97 | 476832.33 | 518.92 | ONE_LAYER | No | No | 0.25 | 3Q (1.3333) | 236.5 | 3Q (1.33) | 243 | NA | NA | 3Q (1.33) | 239 |
| 222 | 2015 | MW | 1348732 | 476178 | 496.775 | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 89.5 | 3Q (1.33) | 282 | NA | NA | 3Q (1.33) | 239 |
| 223 | 2016 | MW | 1347688.79 | 477644.72 | 508.91 | ONE_LAYER | No | Yes | 0.5 | 2Q (2) | 169.5 | 3Q (1.33) | 236 | NA | NA | 3Q (1.33) | 239 |
| 224 | 2017 | MW | 1347688.13 | 476288.53 | 511.295 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 100 | 3Q (1.33) | 229 | NA | NA | 3Q (1.33) | 239 |
| 225 | 2020 | MW | 1348050.37 | 479198.11 | 512.11 | ONE_LAYER | Yes | Yes | 1 | 12Q (0.3333) | 1112 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 226 | 2027 | MW | 1347848.34 | 481998.67 | 518.4 | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 112 | 8Q (0.5) | 704 | NA | NA | 3Q (1.33) | 239 |
| 228 | 2032 | MW | 1346829.58 | 480533.04 | 522.5 | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 123 | 2Q (2) | 222 | NA | NA | 3Q (1.33) | 239 |
| 229 | 2033 | MW | 1347218.32 | 480440.46 | 520.365 | ONE_LAYER | Yes | Yes | 1 | 2Q (2) | 142.5 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 230 | 2034 | MW | 1346950.44 | 480269.41 | 518.3 | ONE_LAYER | Yes | Yes | 1 | 2Q (2) | 143 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 231 | 2037 | MW | 1348332.04 | 482170.36 | 517.29 | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 104 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 232 | 2045 | MW | 1348291 | 477158.9 | 516.01 | ONE_LAYER | No | No | 0.25 | 1Q (4) | 98.5 | 2Q (2) | 205 | NA | NA | 3Q (1.33) | 239 |
| 233 | 2046 | MW | 1347949.69 | 478087.8 | 516.075 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 100.5 | 2Q (2) | 184 | NA | NA | 3Q (1.33) | 239 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 235 | 2048 | MW | 1348397.57 | 477509.58 | 515.26 | ONE_LAYER | No | No | 0.25 | 2Q (2) | 167.5 | 4Q (1) | 335 | NA | NA | 3Q (1.33) | 239 |
| 236 | 2049 | MW | 1348603.06 | 477049.86 | 516.665 | ONE_LAYER | No | No | 0 | 1Q (4) | 95 | 2Q (2) | 210 | NA | NA | 3Q (1.33) | 239 |
| 237 | 2051 | MW | 1351810.93 | 481626.48 | 516.245 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 92 | 3Q (1.33) | 244 | NA | NA | 3Q (1.33) | 239 |
| 238 | 2052 | MW | 1348670.69 | 482536.56 | 518.255 | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 239 | 2054 | MW | 1350054.34 | 480060.21 | 511.66 | ONE_LAYER | Yes | Yes | 1 | 2Q (2) | 163.5 | 3Q (1.33) | 292 | NA | NA | 3Q (1.33) | 239 |
| 240 | 2055 | MW | 1349234.96 | 481517.48 | 517.57 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 241 | 2060 | MW | 1348541.64 | 475894.93 | 497.86 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 97 | 4Q (1) | 336 | NA | NA | 3Q (1.33) | 239 |
| 242 | 2065 | MW | 1348965.38 | 477895.87 | 518.365 | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 243 | 2066 | MW | 1345234.4 | 483968.32 | 526.79 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 244 | 2067 | MW | 1351527.98 | 479790.41 | 525.7 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 245 | 2068 | MW | 1349920.56 | 478712.24 | 489.65 | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 91.5 | 2Q (2) | 195 | NA | NA | 3Q (1.33) | 239 |
| 246 | 2070 | MW | 1350560.02 | 476781.37 | 495.725 | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 91 | 3Q (1.33) | 240 | NA | NA | 3Q (1.33) | 239 |
| 248 | 2093 | MW | 1349934.32 | 475346.64 | 517.1 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 103 | 3Q (1.33) | 305 | NA | NA | 3Q (1.33) | 239 |
| 249 | 2094 | MW | 1349232.77 | 470861.78 | 502.465 | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 250 | 2095 | MW | 1348099.76 | 475081.36 | 517.45 | ONE_LAYER | No | No | 0.25 | 1Q (4) | 99 | 3Q (1.33) | 310 | NA | NA | 3Q (1.33) | 239 |
| 251 | 2097 | MW | 1355466.97 | 480313.09 | 512.79 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 252 | 21033 | MW | 1348712.21 | 477307.46 | 520.365 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 102 | 4Q (1) | 348 | NA | NA | 3Q (1.33) | 239 |
| 254 | 2106 | MW | 1348111 | 476125.6 | 517.285 | ONE_LAYER | No | No | 0.25 | 1Q (4) | 95 | 3Q (1.33) | 268 | NA | NA | 3Q (1.33) | 239 |
| 255 | 21063 | MW | 1350113.03 | 475868.6 | 489.565 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 104.5 | 4Q (1) | 356 | NA | NA | 3Q (1.33) | 239 |
| 256 | 21064 | MW | 1348013.6 | 478472.83 | 521.81 | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 257 | 21065 | MW | 1348568.48 | 478512.65 | 521.26 | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 258 | 2108 | MW | 1346451.72 | 480085.72 | 520.775 | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 259 | 2109 | MW | 1350329.36 | 480521.75 | 512.58 | ONE_LAYER | Yes | Yes | 1 | 2Q (2) | 163 | 2Q (2) | 186 | NA | NA | 3Q (1.33) | 239 |
| 260 | 2118 | MW | 1350326.85 | 480042.54 | 514.695 | ONE_LAYER | Yes | Yes | 1 | 2Q (2) | 163.5 | 4Q (1) | 350 | NA | NA | 3Q (1.33) | 239 |
| 261 | 21192 | MW | 1348173.11 | 477051.86 | 524.215 | ONE_LAYER | No | Yes | 0.5 | 6Q (0.6667) | 512 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 263 | 21194 | MW | 1348131 | 474373 | | ONE_LAYER | No | No | 0 | 1Q (4) | 91 | 2Q (2) | 146 | NA | NA | 3Q (1.33) | 239 |
| 264 | 2125 | MW | 1348010.5 | 474384.26 | 516.065 | ONE_LAYER | No | No | 0.25 | 1Q (4) | 99 | 3Q (1.33) | 301 | NA | NA | 3Q (1.33) | 239 |
| 265 | 2128 | MW | 1348326.82 | 473581.42 | 513.185 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 112 | 3Q (1.33) | 239 | NA | NA | 3Q (1.33) | 239 |
| 266 | 2129 | MW | 1348415.57 | 472662.29 | 511.965 | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 267 | 2166 | MW | 1349637 | 476553.3 | 502.27 | ONE_LAYER | No | No | 0.25 | 1Q (4) | 99 | 3Q (1.33) | 229 | NA | NA | 3Q (1.33) | 239 |
| 273 | 22198 | MW | 1351806.05 | 483093.25 | 521.465 | ONE_LAYER | No | No | 0.25 | 1Q (4) | 50.5 | 2Q (2) | 137 | NA | NA | 3Q (1.33) | 239 |
| 274 | 22199 | MW | 1351807.11 | 482666.74 | 511.775 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 84 | 4Q (1) | 332 | NA | NA | 3Q (1.33) | 239 |
| 275 | 22200 | MW | 1350514.75 | 482614.38 | 517.335 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 90.5 | 3Q (1.33) | 302 | NA | NA | 3Q (1.33) | 239 |
| 276 | 22201 | MW | 1350470.49 | 483091.6 | 527.82 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 90.5 | 3Q (1.33) | 228 | NA | NA | 3Q (1.33) | 239 |
| 277 | 22203 | MW | 1350621.64 | 482193.12 | 513.4 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 89.5 | 3Q (1.33) | 269 | NA | NA | 3Q (1.33) | 239 |
| 278 | 22204 | MW | 1351806.07 | 482251.49 | 533.125 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 78.5 | 2Q (2) | 218 | NA | NA | 3Q (1.33) | 239 |
| 279 | 22205 | MW | 1351808.8 | 481892.92 | 533.31 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 43 | 1Q (4) | 86 | NA | NA | 3Q (1.33) | 239 |
| 280 | 22206 | MW | 1350620.28 | 481680.74 | 511.175 | ONE_LAYER | No | Yes | 0.6667 | 1Q (4) | 60 | 2Q (2) | 213 | NA | NA | 3Q (1.33) | 239 |
| 281 | 22207 | MW | 1350612.02 | 481348.25 | 511.635 | ONE_LAYER | No | Yes | 0.6667 | 1Q (4) | 60 | 7Q (0.57) | 640 | NA | NA | 3Q (1.33) | 239 |
| 282 | 22208 | MW | 1351787.18 | 481374.65 | 510.12 | ONE_LAYER | No | Yes | 0.6667 | 1Q (4) | 43 | 2Q (2) | 153 | NA | NA | 3Q (1.33) | 239 |
| 283 | 22209 | MW | 1350603.17 | 480928.18 | 512 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 56 | 1Q (4) | 119 | NA | NA | 3Q (1.33) | 239 |
| 284 | 22210 | MW | 1351756.46 | 480998.09 | 512.495 | ONE_LAYER | No | Yes | 0.6667 | 1Q (4) | 42 | 1Q (4) | 122 | NA | NA | 3Q (1.33) | 239 |
| 285 | 22211 | MW | 1351751.45 | 480568.32 | 511.105 | ONE_LAYER | No | Yes | 0.6667 | 1Q (4) | 49.5 | 1Q (4) | 72 | NA | NA | 3Q (1.33) | 239 |
| 286 | 22212 | MW | 1350607.41 | 480512.23 | 511.515 | ONE_LAYER | No | No | 0.3333 | 1Q (4) | 58 | 1Q (4) | 77 | NA | NA | 3Q (1.33) | 239 |
| 287 | 22213 | MW | 1350589.66 | 480210.73 | 510.95 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 56.5 | 2Q (2) | 151 | NA | NA | 3Q (1.33) | 239 |
| 288 | 22214 | MW | 1351744.19 | 480215.25 | 509.89 | ONE_LAYER | No | No | 0.3333 | 1Q (4) | 49 | 1Q (4) | 78 | NA | NA | 3Q (1.33) | 239 |
| 289 | 22215 | MW | 1350954.92 | 479654.68 | 512.05 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 57.5 | 1Q (4) | 97 | NA | NA | 3Q (1.33) | 239 |
| 290 | 22216 | MW | 1351303.91 | 479635.65 | 511.89 | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 57 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 291 | 22217 | MW | 1351288.96 | 479600.38 | 512.345 | ONE_LAYER | No | No | 0 | 1Q (4) | 62.5 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 293 | 22299 | MW | 1347976 | 476215.3 | 508.085 | ONE_LAYER | No | No | 0 | 1Q (4) | 91.5 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 294 | 22300 | MW | 1348374 | 476246.4 | 506.665 | ONE_LAYER | No | No | 0 | 1Q (4) | 91.5 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 295 | 22301 | MW | 1348844 | 476183.6 | 506.99 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 91 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 296 | 22302 | MW | 1349374.36 | 476345.87 | 490.525 | ONE_LAYER | No | No | 0 | 1Q (4) | 91 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 297 | 22303 | MW | 1350130 | 476499.1 | 517.895 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 88 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 298 | 23064 | MW | 1347629.56 | 475112.96 | 516.195 | ONE_LAYER | No | Yes | 1 | 2Q (2) | 175 | 2Q (2) | 215 | NA | NA | 3Q (1.33) | 239 |
| 299 | 23118 | MW | 1348076.03 | 480176.97 | 512.215 | ONE_LAYER | No | Yes | 0.6667 | 1Q (4) | 118 | 2Q (2) | 189 | NA | NA | 3Q (1.33) | 239 |
| 300 | 23271 | MW | 1349554 | 478465 | 516.28 | ONE_LAYER | No | Yes | 0.6667 | 2Q (2) | 176 | 3Q (1.33) | 256 | NA | NA | 3Q (1.33) | 239 |
| 301 | 23272 | MW | 1349750.03 | 478318.04 | 516.915 | ONE_LAYER | No | Yes | 0.6667 | 2Q (2) | 176 | 4Q (1) | 402 | NA | NA | 3Q (1.33) | 239 |
| 302 | 23273 | MW | 1349530.08 | 478143.34 | 515.44 | ONE_LAYER | No | Yes | 0.6667 | 2Q (2) | 160 | 3Q (1.33) | 256 | NA | NA | 3Q (1.33) | 239 |
| 303 | 23274 | MW | 1349406.03 | 478336.97 | 515.765 | ONE_LAYER | No | No | 0.3333 | 2Q (2) | 176 | 8Q (0.5) | 704 | NA | NA | 3Q (1.33) | 239 |
| 304 | 23275 | MW | 1349160.8 | 477907 | 516.245 | ONE_LAYER | No | No | 0.3333 | 2Q (2) | 177.5 | 5Q (0.8) | 437 | NA | NA | 3Q (1.33) | 239 |
| 305 | 23276 | MW | 1348808.43 | 477675.11 | 516.695 | ONE_LAYER | No | Yes | 1 | 2Q (2) | 175 | 2Q (2) | 193 | NA | NA | 3Q (1.33) | 239 |
| 306 | 23277 | MW | 1348843.8 | 478102.89 | 516.495 | ONE_LAYER | No | No | 0.3333 | 2Q (2) | 167 | 6Q (0.67) | 534 | NA | NA | 3Q (1.33) | 239 |
| 307 | 23278 | MW | 1348653.55 | 477923.31 | 516.35 | ONE_LAYER | No | Yes | 0.6667 | 2Q (2) | 167 | 2Q (2) | 214 | NA | NA | 3Q (1.33) | 239 |
| 308 | 23279 | MW | 1348394.4 | 478191.54 | 516.54 | ONE_LAYER | No | Yes | 0.6667 | 2Q (2) | 170 | 8Q (0.5) | 680 | NA | NA | 3Q (1.33) | 239 |
| 309 | 23280 | MW | 1348156.94 | 478017.01 | 516.305 | ONE_LAYER | No | Yes | 1 | 2Q (2) | 168 | 2Q (2) | 224 | NA | NA | 3Q (1.33) | 239 |
| 310 | 23281 | MW | 1347953.05 | 477817.04 | 516.225 | ONE_LAYER | No | No | 0.3333 | 2Q (2) | 175 | 3Q (1.33) | 243 | NA | NA | 3Q (1.33) | 239 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 311 | 23282 | MW | 1348151.13 | 477622.06 | 516.58 | ONE_LAYER | No | Yes | 0.6667 | 2Q (2) | 175 | 4Q (1) | 329 | NA | NA | 3Q (1.33) | 239 |
| 312 | 2385 | MW | 1348454.26 | 477915.86 | 518.23 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 104.5 | 4Q (1) | 348 | NA | NA | 3Q (1.33) | 239 |
| 313 | 2386 | MW | 1349314.99 | 477663.26 | 518.06 | ONE_LAYER | No | No | 0 | 1Q (4) | 100.5 | 3Q (1.33) | 252 | NA | NA | 3Q (1.33) | 239 |
| 314 | 2387 | MW | 1348972.17 | 477148.47 | 517.395 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 101 | 3Q (1.33) | 263 | NA | NA | 3Q (1.33) | 239 |
| 315 | 2388 | MW | 1349955.83 | 480512.56 | 520.515 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 316 | 2389 | MW | 1349853.25 | 480173.3 | 519.115 | ONE_LAYER | No | No | 0 | 2Q (2) | 174 | 3Q (1.33) | 226 | NA | NA | 3Q (1.33) | 239 |
| 317 | 2390 | MW | 1348406 | 476577.2 | 518.795 | ONE_LAYER | No | No | 0.25 | 1Q (4) | 101 | 4Q (1) | 343 | NA | NA | 3Q (1.33) | 239 |
| 318 | 2391 | MW | 1350018.9 | 472174.3 | 510.575 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 319 | 2392 | MW | 1350111.6 | 471451.67 | 504.06 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 320 | 2393 | MW | 1347910.87 | 472656.87 | 511.515 | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 321 | 2395 | MW | 1350659.39 | 471714.41 | 507.445 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 322 | 2396 | MW | 1347744.58 | 474199.06 | 516.205 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 98 | 4Q (1) | 376 | NA | NA | 3Q (1.33) | 239 |
| 323 | 2397 | MW | 1349526.06 | 478300.02 | 521.125 | ONE_LAYER | No | Yes | 0.75 | 2Q (2) | 150 | 2Q (2) | 141 | NA | NA | 3Q (1.33) | 239 |
| 324 | 2398 | MW | 1349877 | 476618.7 | 517.205 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 105 | 4Q (1) | 368 | NA | NA | 3Q (1.33) | 239 |
| 325 | 2399 | MW | 1350079.81 | 477343.94 | 515.64 | ONE_LAYER | No | No | 0 | 8Q (0.5) | 706 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 326 | 2400 | MW | 1350346.82 | 477928.86 | 514.415 | ONE_LAYER | Yes | Yes | 1 | 5Q (0.8) | 468 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 327 | 2402 | MW | 1347307.57 | 478222.82 | 515.015 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 100.5 | 3Q (1.33) | 281 | NA | NA | 3Q (1.33) | 239 |
| 328 | 2417 | MW | 1351464.84 | 480332.9 | 516.715 | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 92 | 1Q (4) | 133 | NA | NA | 3Q (1.33) | 239 |
| 330 | 2421 | MW | 1350605.32 | 481681.26 | 515.42 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 331 | 2423 | MW | 1350301.63 | 482585.94 | 505.655 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 332 | 2424 | MW | 1351811.93 | 482376.45 | 517.47 | ONE_LAYER | No | No | 0 | 1Q (4) | 93 | 1Q (4) | 123 | NA | NA | 3Q (1.33) | 239 |
| 333 | 2426 | MW | 1351733.7 | 480850.24 | 520.16 | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 97 | 2Q (2) | 163 | NA | NA | 3Q (1.33) | 239 |
| 334 | 2429 | MW | 1351824.02 | 480112.01 | 519.54 | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 97 | 3Q (1.33) | 245 | NA | NA | 3Q (1.33) | 239 |
| 335 | 2430 | MW | 1351528.3 | 479783.18 | 519.15 | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 97 | 2Q (2) | 207 | NA | NA | 3Q (1.33) | 239 |
| 336 | 2431 | MW | 1351606.01 | 478886.2 | 517.61 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 97.5 | 2Q (2) | 194 | NA | NA | 3Q (1.33) | 239 |
| 337 | 2432 | MW | 1351613.27 | 478031.61 | 519.04 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 97.5 | 3Q (1.33) | 245 | NA | NA | 3Q (1.33) | 239 |
| 338 | 2434 | MW | 1349246 | 476441.3 | 516.37 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 91 | 7Q (0.57) | 672 | NA | NA | 3Q (1.33) | 239 |
| 340 | 2454 | MW | 1347841.22 | 481230.43 | 525.59 | ONE_LAYER | Yes | Yes | 1 | 23Q (0.1739) | 2083 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 341 | 2544 | MW | 1348506.45 | 474565.31 | 519.13 | ONE_LAYER | No | No | 0 | NA (NA) | NA | 2Q (2) | 138 | NA | NA | 3Q (1.33) | 239 |
| 342 | 2545 | MW | 1348010.81 | 474203.21 | 515.295 | ONE_LAYER | No | Yes | 0.5 | 3Q (1.3333) | 276 | 2Q (2) | 142 | NA | NA | 3Q (1.33) | 239 |
| 343 | 2546 | MW | 1348061.81 | 473477.9 | 512.92 | ONE_LAYER | No | No | 0 | 1Q (4) | 91 | 6Q (0.67) | 582 | NA | NA | 3Q (1.33) | 239 |
| 344 | 2550 | MW | 1347879 | 475784.4 | 520.49 | ONE_LAYER | No | Yes | 0.75 | 2Q (2) | 135 | 12Q (0.33) | 1040 | NA | NA | 3Q (1.33) | 239 |
| 345 | 2551 | MW | 1347536.99 | 475376.68 | 516.33 | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 92 | 2Q (2) | 171 | NA | NA | 3Q (1.33) | 239 |
| 346 | 2552 | MW | 1347726.38 | 473939.13 | 514.41 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 98 | 3Q (1.33) | 252 | NA | NA | 3Q (1.33) | 239 |
| 347 | 2553 | MW | 1347416.67 | 473372.41 | 515.07 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 98 | 3Q (1.33) | 255 | NA | NA | 3Q (1.33) | 239 |
| 348 | 2554 | MW | 1347475.06 | 472232.01 | 509.97 | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 349 | 2555 | MW | 1346642.88 | 472609.67 | 516.21 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 350 | 2556 | MW | 1348173.84 | 471293.13 | 504.825 | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 351 | 2558 | MW | 1348461.89 | 469212.96 | 502.165 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 352 | 2559 | MW | 1349124.48 | 469990.27 | 501.96 | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 353 | 2560 | MW | 1348244.96 | 468787.66 | 509.98 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 354 | 2625 | MW | 1348227.6 | 473734.15 | 520.245 | ONE_LAYER | No | Yes | 1 | 4Q (1) | 349.5 | 2Q (2) | 209 | NA | NA | 3Q (1.33) | 239 |
| 355 | 2636 | MW | 1348486.14 | 473406.39 | 519.625 | ONE_LAYER | No | Yes | 0.75 | 7Q (0.5714) | 660 | 4Q (1) | 336 | NA | NA | 3Q (1.33) | 239 |
| 357 | 2648 | MW | 1347593.54 | 481537.67 | 519.795 | ONE_LAYER | Yes | Yes | 1 | 2Q (2) | 163 | 3Q (1.33) | 311 | NA | NA | 3Q (1.33) | 239 |
| 358 | 2649 | MW | 1346656.71 | 481196.78 | 502.775 | ONE_LAYER | No | Yes | 0.5 | 2Q (2) | 160 | 3Q (1.33) | 266 | NA | NA | 3Q (1.33) | 239 |
| 359 | 2728 | MW | 1346491.55 | 483331.01 | 518.675 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 360 | 2733 | MW | 1351692.04 | 477100.05 | 521.88 | ONE_LAYER | No | Yes | 0.5 | 2Q (2) | 181 | 3Q (1.33) | 285 | NA | NA | 3Q (1.33) | 239 |
| 362 | 2821 | MW | 1347156.19 | 481366.6 | 513.205 | ONE_LAYER | No | Yes | 0.5 | 2Q (2) | 167.5 | 8Q (0.5) | 696 | NA | NA | 3Q (1.33) | 239 |
| 363 | 2880 | MW | 1348599 | 475062.1 | 519.73 | ONE_LAYER | No | No | 0.25 | 2Q (2) | 179.5 | 4Q (1) | 395 | NA | NA | 3Q (1.33) | 239 |
| 364 | 2881 | MW | 1349094 | 475046.3 | 519.995 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 92 | 1Q (4) | 128 | NA | NA | 3Q (1.33) | 239 |
| 365 | 2897 | MW | 1349433 | 475010 | 519.19 | ONE_LAYER | No | Yes | 0.75 | 2Q (2) | 163 | 8Q (0.5) | 745 | NA | NA | 3Q (1.33) | 239 |
| 366 | 2898 | MW | 1349829.81 | 474398.44 | 517.46 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 111.5 | 3Q (1.33) | 238 | NA | NA | 3Q (1.33) | 239 |
| 367 | 2899 | MW | 1349225.8 | 474167.73 | 518.62 | ONE_LAYER | No | No | 0.25 | 2Q (2) | 175 | 4Q (1) | 374 | NA | NA | 3Q (1.33) | 239 |
| 369 | 2900 | MW | 1348453.69 | 473949.42 | 517.375 | ONE_LAYER | No | No | 0.25 | 1Q (4) | 112 | 2Q (2) | 197 | NA | NA | 3Q (1.33) | 239 |
| 370 | 2936 | MW | 1348393.07 | 480706.95 | 520.285 | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 374 | 3009 | MW | 1346554.78 | 479581.27 | 457.145 | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 101 | 4Q (1) | 373 | NA | NA | 3Q (1.33) | 239 |
| 375 | 3014 | MW | 1348110.27 | 476834.65 | 489.435 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 101.5 | 3Q (1.33) | 282 | NA | NA | 3Q (1.33) | 239 |
| 376 | 3015 | MW | 1348732 | 476165.4 | 458.665 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 99 | 11Q (0.36) | 1024 | NA | NA | 3Q (1.33) | 239 |
| 377 | 3020 | MW | 1348066.37 | 479196.77 | 460.54 | ONE_LAYER | Yes | Yes | 1 | 3Q (1.3333) | 256 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 378 | 3027 | MW | 1347839.27 | 482004.46 | 465.675 | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 119 | 2Q (2) | 165 | NA | NA | 3Q (1.33) | 239 |
| 379 | 3032 | MW | 1346827.61 | 480522.14 | 457.45 | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 123 | 3Q (1.33) | 260 | NA | NA | 3Q (1.33) | 239 |
| 380 | 3034 | MW | 1346962.38 | 480269.59 | 466.035 | ONE_LAYER | Yes | Yes | 1 | 2Q (2) | 143 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 381 | 3037 | MW | 1348322.93 | 482170.82 | 460.625 | ONE_LAYER | Yes | Yes | 1 | 13Q (0.3077) | 1194 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 382 | 3043 | MW | 1345581.33 | 481800.26 | 466.85 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 383 | 3044 | MW | 1346693.81 | 477802.9 | 455.085 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 384 | 3045 | MW | 1348273 | 477168.8 | 459.135 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 100.5 | 6Q (0.67) | 523 | NA | NA | 3Q (1.33) | 239 |
| 385 | 3046 | MW | 1347969.67 | 478080.58 | 457.855 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 100.5 | 3Q (1.33) | 260 | NA | NA | 3Q (1.33) | 239 |
| 386 | 3049 | MW | 1348592.44 | 477050.57 | 458.91 | ONE_LAYER | No | No | 0.25 | 1Q (4) | 101.5 | 3Q (1.33) | 304 | NA | NA | 3Q (1.33) | 239 |
| 387 | 3054 | MW | 1350055.45 | 480069.69 | 465.205 | ONE_LAYER | Yes | Yes | 1 | 2Q (2) | 163.5 | 2Q (2) | 187 | NA | NA | 3Q (1.33) | 239 |
| 388 | 3055 | MW | 1349233.52 | 481494.21 | 472.235 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 389 | 3065 | MW | 1348937.97 | 477885.44 | 457.83 | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 390 | 3066 | MW | 1345237.19 | 483980.66 | 449.28 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 391 | 3067 | MW | 1351519.16 | 479789.54 | 470.58 | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 96 | 11Q (0.36) | 1024 | NA | NA | 3Q (1.33) | 239 |
| 392 | 3068 | MW | 1349922.41 | 478701.81 | 453.415 | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 92 | 1Q (4) | 134 | NA | NA | 3Q (1.33) | 239 |
| 393 | 3069 | MW | 1349245 | 476451.5 | 455.375 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 96.5 | 2Q (2) | 210 | NA | NA | 3Q (1.33) | 239 |
| 394 | 3070 | MW | 1350557.08 | 476791.6 | 457.815 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 96 | 3Q (1.33) | 293 | NA | NA | 3Q (1.33) | 239 |
| 395 | 3091 | MW | 1352985.06 | 477864.68 | 449.305 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 396 | 3092 | MW | 1352716.49 | 476641.02 | 456.495 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 397 | 3093 | MW | 1349920.96 | 475347.76 | 449.37 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 104 | 3Q (1.33) | 277 | NA | NA | 3Q (1.33) | 239 |
| 398 | 3094 | MW | 1349245.35 | 470867.82 | 455.29 | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 399 | 3095 | MW | 1348088.11 | 475078.7 | 459.91 | ONE_LAYER | No | No | 0.25 | 1Q (4) | 99 | 12Q (0.33) | 1035 | NA | NA | 3Q (1.33) | 239 |
| 400 | 3097 | MW | 1355474.14 | 480320.42 | 452.45 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 401 | 3098 | MW | 1354845.58 | 483416.41 | 453.945 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 402 | 3106 | MW | 1348120 | 476123.3 | 458.13 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 97 | 3Q (1.33) | 265 | NA | NA | 3Q (1.33) | 239 |
| 403 | 3107 | MW | 1347063.94 | 478587.93 | 459.66 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 404 | 3108 | MW | 1346458.11 | 480089.4 | 462.97 | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 405 | 31217 | MW | 1351748 | 481636.4 | 448.08 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 98 | 8Q (0.5) | 744 | NA | NA | 3Q (1.33) | 239 |
| 406 | 3125 | MW | 1348010.88 | 474373.84 | 460.695 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 99 | 2Q (2) | 198 | NA | NA | 3Q (1.33) | 239 |
| 407 | 3126 | MW | 1347492.26 | 473067.96 | 456.695 | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 408 | 3128 | MW | 1348329.4 | 473571.15 | 461.995 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 97 | 4Q (1) | 378 | NA | NA | 3Q (1.33) | 239 |
| 409 | 31550 | EXW | 1348980 | 477018.5 | 499.425 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 7 | 1Q (4) | 56 | NA | NA | 3Q (1.33) | 239 |
| 410 | 31560 | EXW | 1349029 | 477403.1 | 500.005 | ONE_LAYER | No | No | 0 | 1Q (4) | 7 | 1Q (4) | 75 | NA | NA | 3Q (1.33) | 239 |
| 411 | 31561 | EXW | 1349255 | 477660.8 | 497.5 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 7 | 1Q (4) | 75 | NA | NA | 3Q (1.33) | 239 |
| 412 | 31562 | EXW | 1349500 | 477953.1 | 494.57 | ONE_LAYER | No | No | 0 | 1Q (4) | 7 | 1Q (4) | 45 | NA | NA | 3Q (1.33) | 239 |
| 413 | 31563 | IJW | 1348330 | 477066.4 | 481.5 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 7 | 1Q (4) | 37 | NA | NA | 3Q (1.33) | 239 |
| 414 | 31564 | EXW | 1347880 | 477124.7 | 498.205 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 7 | 1Q (4) | 45 | NA | NA | 3Q (1.33) | 239 |
| 415 | 31565 | EXW | 1347630 | 477648 | 501.75 | ONE_LAYER | No | No | 0 | 1Q (4) | 7 | 1Q (4) | 37 | NA | NA | 3Q (1.33) | 239 |
| 416 | 31566 | EXW | 1348361 | 477576.1 | 500.49 | ONE_LAYER | No | No | 0 | 1Q (4) | 7 | 1Q (4) | 32 | NA | NA | 3Q (1.33) | 239 |
| 417 | 31567 | EXW | 1348854 | 477905.5 | 504.835 | ONE_LAYER | No | No | 0.25 | 1Q (4) | 7 | 1Q (4) | 56 | NA | NA | 3Q (1.33) | 239 |
| 418 | 32276 | EXW | 1348857 | 476447.3 | 489.345 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 7 | 1Q (4) | 75 | NA | NA | 3Q (1.33) | 239 |
| 419 | 32304 | MW | 1347991 | 476189.3 | 437.96 | ONE_LAYER | No | No | 0 | 1Q (4) | 90 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 420 | 32305 | MW | 1348406 | 476243.7 | 440.115 | ONE_LAYER | No | No | 0 | 1Q (4) | 90 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 421 | 32306 | MW | 1348864 | 476159.1 | 439.65 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 90.5 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 422 | 32307 | MW | 1349385.21 | 476330.96 | 441.3 | ONE_LAYER | No | No | 0 | 1Q (4) | 88 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 423 | 32308 | EXW | 1348693.88 | 475078.83 | 494.78 | ONE_LAYER | No | No | 0 | 1Q (4) | 7 | 1Q (4) | 56 | NA | NA | 3Q (1.33) | 239 |
| 424 | 32309 | EXW | 1348366.34 | 475109.6 | 492.075 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 7 | 1Q (4) | 56 | NA | NA | 3Q (1.33) | 239 |
| 426 | 32446 | EXW | 1349312 | 476634 | 481.805 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 7 | 1Q (4) | 56 | NA | NA | 3Q (1.33) | 239 |
| 427 | 32447 | EXW | 1349421.93 | 477151.41 | 483.07 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 7 | 1Q (4) | 45 | NA | NA | 3Q (1.33) | 239 |
| 428 | 32761 | EXW | 1347364.02 | 479892.36 | 500.05 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 7 | 1Q (4) | 32 | NA | NA | 3Q (1.33) | 239 |
| 429 | 32762 | MW | 1347214.51 | 479929.02 | 506.195 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 430 | 32764 | MW | 1347339.54 | 479896.81 | 492.685 | ONE_LAYER | No | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 431 | 32765 | MW | 1347330.82 | 479906.92 | 437.88 | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 432 | 32766 | MW | 1347459.03 | 479865.7 | 498.49 | ONE_LAYER | No | Yes | 0.6667 | 2Q (2) | 161.5 | 4Q (1) | 345 | NA | NA | 3Q (1.33) | 239 |
| 433 | 32768 | MW | 1347337.16 | 479792.83 | 500.205 | ONE_LAYER | No | No | 0.3333 | 2Q (2) | 161.5 | 4Q (1) | 345 | NA | NA | 3Q (1.33) | 239 |
| 434 | 33061 | EXW | 1349531.03 | 478318.82 | 503.56 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 7 | 1Q (4) | 32 | NA | NA | 3Q (1.33) | 239 |
| 435 | 33062 | EXW | 1348037.2 | 480013.01 | 499.05 | ONE_LAYER | No | No | 0.3333 | 1Q (4) | 7 | 1Q (4) | 37 | NA | NA | 3Q (1.33) | 239 |
| 436 | 33063 | EXW | 1348464.13 | 480001.75 | 499.815 | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 7 | 1Q (4) | 75 | NA | NA | 3Q (1.33) | 239 |
| 437 | 33253 | IJW | 1348187.37 | 476233.52 | 505.25 | ONE_LAYER | No | No | 0 | 1Q (4) | 21 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 438 | 33254 | IJW | 1348618.93 | 476139.64 | 504.365 | ONE_LAYER | No | No | 0 | 1Q (4) | 21 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 439 | 33255 | IJW | 1349088.11 | 476262.66 | 494.41 | ONE_LAYER | No | No | 0 | 1Q (4) | 6 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 440 | 33262 | EXW | 1348149.97 | 477799.91 | 503.37 | ONE_LAYER | No | Yes | 0.6667 | 1Q (4) | 7 | 1Q (4) | 37 | NA | NA | 3Q (1.33) | 239 |
| 441 | 33263 | IJW | 1348048.48 | 478200.28 | 504.925 | ONE_LAYER | No | No | 0 | 1Q (4) | 7 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 442 | 33264 | EXW | 1349751.49 | 477200.95 | 490.22 | ONE_LAYER | No | Yes | 0.6667 | 1Q (4) | 7 | 1Q (4) | 45 | NA | NA | 3Q (1.33) | 239 |
| 443 | 33265 | EXW | 1349849.01 | 477598.91 | 491.97 | ONE_LAYER | No | Yes | 0.6667 | 1Q (4) | 7 | 1Q (4) | 37 | NA | NA | 3Q (1.33) | 239 |
| 444 | 33266 | EXW | 1350046.97 | 476997.58 | 489.93 | ONE_LAYER | No | No | 0 | 1Q (4) | 7 | 1Q (4) | 45 | NA | NA | 3Q (1.33) | 239 |
| 445 | 33298 | EXW | 1349550.59 | 477954.37 | 498.21 | ONE_LAYER | No | No | 0.3333 | 1Q (4) | 7 | 1Q (4) | 32 | NA | NA | 3Q (1.33) | 239 |
| 446 | 33326 | EXW | 1348799.7 | 477882.01 | 506.135 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 7 | 1Q (4) | 25 | NA | NA | 3Q (1.33) | 239 |
| 447 | 33334 | EXW | 1348686.38 | 479918.96 | 489.55 | ONE_LAYER | No | No | 0 | 1Q (4) | 7 | 1Q (4) | 19 | NA | NA | 3Q (1.33) | 239 |
| 448 | 33347 | EXW | 1346715.82 | 481031.76 | 493.86 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 3 | 1Q (4) | 19 | NA | NA | 3Q (1.33) | 239 |
| 449 | 3385 | MW | 1348463.67 | 477912.39 | 458.59 | ONE_LAYER | No | No | 0.25 | 1Q (4) | 101 | 4Q (1) | 392 | NA | NA | 3Q (1.33) | 239 |
| 450 | 3387 | MW | 1348982.67 | 477146.65 | 457.85 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 103 | 4Q (1) | 317 | NA | NA | 3Q (1.33) | 239 |
| 451 | 3390 | MW | 1348411 | 476570 | 461.17 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 102 | 4Q (1) | 392 | NA | NA | 3Q (1.33) | 239 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 452 | 3391 | MW | 1350018.77 | 472184.92 | 458.365 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 453 | 3396 | MW | 1347739.19 | 474190.52 | 454.73 | ONE_LAYER | No | No | 0.25 | 1Q (4) | 98 | 3Q (1.33) | 273 | NA | NA | 3Q (1.33) | 239 |
| 454 | 3397 | MW | 1349534.54 | 478305.8 | 461.275 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 97 | 2Q (2) | 219 | NA | NA | 3Q (1.33) | 239 |
| 455 | 3398 | MW | 1349865 | 476615.3 | 455.39 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 96 | 3Q (1.33) | 293 | NA | NA | 3Q (1.33) | 239 |
| 456 | 3402 | MW | 1347317.5 | 478226.05 | 458.305 | ONE_LAYER | No | No | 0.25 | 1Q (4) | 100.5 | 3Q (1.33) | 238 | NA | NA | 3Q (1.33) | 239 |
| 457 | 3417 | MW | 1351463.44 | 480314.51 | 454.14 | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 91 | 2Q (2) | 225 | NA | NA | 3Q (1.33) | 239 |
| 458 | 3421 | MW | 1350605.7 | 481692.05 | 453.065 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 459 | 3423 | MW | 1350286.71 | 482585.09 | 457.125 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 460 | 3424 | MW | 1351793.59 | 482392.18 | 450.375 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 98 | 3Q (1.33) | 261 | NA | NA | 3Q (1.33) | 239 |
| 461 | 3426 | MW | 1351733.15 | 480860.32 | 450.395 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 98 | 3Q (1.33) | 310 | NA | NA | 3Q (1.33) | 239 |
| 462 | 3429 | MW | 1351823.86 | 480102.34 | 444.55 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 101 | 4Q (1) | 388 | NA | NA | 3Q (1.33) | 239 |
| 463 | 3431 | MW | 1351606.72 | 478895.98 | 448.455 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 97.5 | 3Q (1.33) | 248 | NA | NA | 3Q (1.33) | 239 |
| 464 | 3432 | MW | 1351615.3 | 478044.38 | 449.915 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 98 | 17Q (0.24) | 1488 | NA | NA | 3Q (1.33) | 239 |
| 465 | 3550 | MW | 1347878 | 475794.6 | 460.68 | ONE_LAYER | No | No | 0.25 | 1Q (4) | 111 | 3Q (1.33) | 261 | NA | NA | 3Q (1.33) | 239 |
| 466 | 3551 | MW | 1347536.98 | 475366.2 | 451.465 | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 92 | 2Q (2) | 208 | NA | NA | 3Q (1.33) | 239 |
| 467 | 3552 | MW | 1347717.98 | 473932.09 | 451.555 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 98 | 11Q (0.36) | 1008 | NA | NA | 3Q (1.33) | 239 |
| 468 | 3636 | MW | 1348493.34 | 473409.73 | 456.42 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 101.5 | 4Q (1) | 341 | NA | NA | 3Q (1.33) | 239 |
| 469 | 3678 | MW | 1349442.45 | 483079.52 | 499.165 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 470 | 3679 | MW | 1346781.45 | 483956.17 | 475.87 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 471 | 3733 | MW | 1351676.36 | 477096.63 | 450.605 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 98 | 4Q (1) | 331 | NA | NA | 3Q (1.33) | 239 |
| 472 | 3821 | MW | 1347161.86 | 481375.34 | 475.97 | ONE_LAYER | No | Yes | 0.75 | 2Q (2) | 167.5 | 14Q (0.29) | 1288 | NA | NA | 3Q (1.33) | 239 |
| 473 | 3880 | MW | 1348609 | 475063.6 | 453.01 | ONE_LAYER | No | No | 0.25 | 2Q (2) | 183 | 4Q (1) | 384 | NA | NA | 3Q (1.33) | 239 |
| 474 | 3881 | MW | 1349082 | 475047.3 | 451.08 | ONE_LAYER | No | No | 0 | 1Q (4) | 91 | 1Q (4) | 123 | NA | NA | 3Q (1.33) | 239 |
| 475 | 3897 | MW | 1349432 | 475000.4 | 453.96 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 102.5 | 2Q (2) | 217 | NA | NA | 3Q (1.33) | 239 |
| 476 | 3898 | MW | 1349829.13 | 474409.84 | 450.705 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 96 | 3Q (1.33) | 246 | NA | NA | 3Q (1.33) | 239 |
| 477 | 3899 | MW | 1349216.88 | 474148.04 | 450.4 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 101 | 4Q (1) | 341 | NA | NA | 3Q (1.33) | 239 |
| 478 | 3900 | MW | 1348487.38 | 473933.67 | 451.14 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 104 | 3Q (1.33) | 242 | NA | NA | 3Q (1.33) | 239 |
| 479 | 3924 | EXW | 1348314.26 | 474219.7 | 496.9 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 7 | 1Q (4) | 75 | NA | NA | 3Q (1.33) | 239 |
| 480 | 3925 | EXW | 1348565.4 | 474319.65 | 495.3 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 7 | 1Q (4) | 75 | NA | NA | 3Q (1.33) | 239 |
| 481 | 3926 | EXW | 1348837.52 | 474428.56 | 496 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 7 | 1Q (4) | 56 | NA | NA | 3Q (1.33) | 239 |
| 482 | 3927 | EXW | 1349127.27 | 474541.83 | 495 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 7 | 1Q (4) | 75 | NA | NA | 3Q (1.33) | 239 |
| 485 | 4010 | MW | 1348230.13 | 481484.83 | 387.765 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 486 | 4011 | MW | 1346486.35 | 482286.46 | 408.995 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 487 | 4013 | MW | 1350547.78 | 481688.71 | 385.7 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 488 | 4067 | MW | 1351525.38 | 479802.02 | 390.445 | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 94.5 | 2Q (2) | 157 | NA | NA | 3Q (1.33) | 239 |
| 489 | 4091 | MW | 1352990.58 | 477873.1 | 411.47 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 490 | 4097 | MW | 1355480.92 | 480327.45 | 402.42 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 491 | 4103 | EXW | 1348381.99 | 479958.37 | 368.77 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 492 | 41066 | MW | 1349820.3 | 482055.59 | 386.585 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 493 | 41217 | MW | 1351750 | 481605.1 | 382.925 | ONE_LAYER | No | No | 0 | 1Q (4) | 92 | 2Q (2) | 210 | NA | NA | 3Q (1.33) | 239 |
| 494 | 4125 | MW | 1348012.83 | 474396.32 | 425.605 | ONE_LAYER | No | No | 0.25 | 1Q (4) | 99 | 16Q (0.25) | 1472 | NA | NA | 3Q (1.33) | 239 |
| 496 | 43309 | EXW | 1351619.22 | 479293.95 | 432.335 | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 497 | 4398 | MW | 1349873 | 476609.2 | 400.45 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 96 | 16Q (0.25) | 1456 | NA | NA | 3Q (1.33) | 239 |
| 498 | 4424 | MW | 1351803.87 | 482384.26 | 380.115 | ONE_LAYER | No | No | 0 | 1Q (4) | 93 | 2Q (2) | 173 | NA | NA | 3Q (1.33) | 239 |
| 499 | 4426 | MW | 1351724.77 | 480865.66 | 392.475 | ONE_LAYER | No | No | 0 | 1Q (4) | 91 | 6Q (0.67) | 582 | NA | NA | 3Q (1.33) | 239 |
| 500 | 4432 | MW | 1351620.83 | 478054.67 | 407.01 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 92 | 2Q (2) | 182 | NA | NA | 3Q (1.33) | 239 |
| 501 | 4451 | MW | 1348547.52 | 479410.44 | 387.055 | ONE_LAYER | Yes | Yes | 1 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 502 | 6015 | MW | 1348725 | 476193.9 | 500.155 | ONE_LAYER | No | Yes | 1 | 2Q (2) | 185.5 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 503 | 62408 | MW | 1349819.79 | 477796.7 | 500 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 107.5 | 2Q (2) | 181 | NA | NA | 3Q (1.33) | 239 |
| 504 | 62433 | MW | 1349732.94 | 477179.25 | 498.01 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 104 | 2Q (2) | 196 | NA | NA | 3Q (1.33) | 239 |
| 505 | 63116 | MW | 1347429.53 | 480047.3 | 506.635 | ONE_LAYER | No | Yes | 0.6667 | 2Q (2) | 140 | 2Q (2) | 224 | NA | NA | 3Q (1.33) | 239 |
| 506 | 63119 | MW | 1348039.48 | 479857.69 | 500.835 | ONE_LAYER | No | Yes | 0.6667 | 2Q (2) | 145 | 4Q (1) | 357 | NA | NA | 3Q (1.33) | 239 |
| 507 | 63121 | MW | 1348580.84 | 480194.17 | 506.11 | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 117 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 508 | 63122 | MW | 1348454.13 | 479757.73 | 496.38 | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 124 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 509 | 63283 | MW | 1349212.62 | 477077.03 | 489.715 | ONE_LAYER | No | Yes | 1 | 2Q (2) | 173 | 3Q (1.33) | 291 | NA | NA | 3Q (1.33) | 239 |
| 510 | 63284 | MW | 1349675.45 | 477942.26 | 502.865 | ONE_LAYER | No | No | 0.3333 | 2Q (2) | 160 | 2Q (2) | 223 | NA | NA | 3Q (1.33) | 239 |
| 511 | 63285 | MW | 1349552.06 | 477665.04 | 501.125 | ONE_LAYER | No | Yes | 0.6667 | 2Q (2) | 160 | 3Q (1.33) | 269 | NA | NA | 3Q (1.33) | 239 |
| 512 | 63286 | MW | 1350066.92 | 477594.05 | 501.175 | ONE_LAYER | No | Yes | 1 | 2Q (2) | 164 | 10Q (0.4) | 875 | NA | NA | 3Q (1.33) | 239 |
| 513 | 63287 | MW | 1349804.16 | 477406.38 | 501.13 | ONE_LAYER | No | Yes | 1 | 2Q (2) | 160 | 4Q (1) | 366 | NA | NA | 3Q (1.33) | 239 |
| 514 | 63288 | MW | 1349851.02 | 477000.11 | 487.755 | ONE_LAYER | No | Yes | 0.6667 | 2Q (2) | 148 | 2Q (2) | 182 | NA | NA | 3Q (1.33) | 239 |
| 515 | 63289 | MW | 1350247.04 | 476996.99 | 486.98 | ONE_LAYER | No | Yes | 0.6667 | 2Q (2) | 172 | 4Q (1) | 344 | NA | NA | 3Q (1.33) | 239 |
| 516 | 63290 | MW | 1350047.94 | 476802.02 | 487.85 | ONE_LAYER | No | Yes | 0.6667 | 2Q (2) | 172 | 5Q (0.8) | 459 | NA | NA | 3Q (1.33) | 239 |
| 517 | 63291 | MW | 1349329 | 477403 | 489.33 | ONE_LAYER | No | Yes | 0.6667 | 2Q (2) | 173 | 3Q (1.33) | 277 | NA | NA | 3Q (1.33) | 239 |
| 518 | 63292 | MW | 1349365 | 476886 | 489.59 | ONE_LAYER | No | Yes | 1 | 2Q (2) | 166 | 2Q (2) | 190 | NA | NA | 3Q (1.33) | 239 |
| 519 | 67 | MW | 1349490.04 | 482138.42 | | ONE_LAYER | Yes | Yes | 1 | 3Q (1.3333) | 239 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 520 | 6880 | MW | 1348588.55 | 475064.47 | 501.84 | ONE_LAYER | No | Yes | 0.75 | 1Q (4) | 100 | 2Q (2) | 200 | NA | NA | 3Q (1.33) | 239 |
| 521 | 6881 | MW | 1349061.87 | 475048.87 | 501.405 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 100 | 5Q (0.8) | 457 | NA | NA | 3Q (1.33) | 239 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 522 | 72433 | MW | 1349768.33 | 477184.6 | 499.765 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 16 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 524 | 82433 | MC | 1349764.71 | 477172.26 | 495.94 | ONE_LAYER | No | No | 0.3333 | 1Q (4) | 26.5 | 4Q (1) | 327 | NA | NA | 3Q (1.33) | 239 |
| 525 | 83117 | MC | 1347773.84 | 479999.15 | 520.82 | ONE_LAYER | No | No | 0 | 1Q (4) | 70 | 2Q (2) | 161 | NA | NA | 3Q (1.33) | 239 |
| 526 | 83120 | MC | 1348312.42 | 480022.35 | 508.59 | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 1 | 1Q (4) | 116 | NA | NA | 3Q (1.33) | 239 |
| 527 | 83123 | MC | 1348757.68 | 480010.95 | 509.29 | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 4.5 | 1Q (4) | 33 | NA | NA | 3Q (1.33) | 239 |
| 528 | 83124 | MC | 1346826.26 | 479977.18 | 521.35 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 36 | 2Q (2) | 173 | NA | NA | 3Q (1.33) | 239 |
| 529 | 83293 | MC | 1349950.71 | 477198.72 | 497.17 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 9 | 2Q (2) | 198 | NA | NA | 3Q (1.33) | 239 |
| 530 | 83294 | MC | 1349599.5 | 477189.53 | 509.5 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 6 | 1Q (4) | 126 | NA | NA | 3Q (1.33) | 239 |
| 531 | 83295 | MC | 1348855.34 | 476626.54 | 508.695 | ONE_LAYER | No | Yes | 0.5 | 1Q (4) | 29 | 2Q (2) | 179 | NA | NA | 3Q (1.33) | 239 |
| 532 | 83296 | MC | 1348641.51 | 476408.89 | 508.89 | ONE_LAYER | No | No | 0.3333 | 1Q (4) | 14 | 2Q (2) | 152 | NA | NA | 3Q (1.33) | 239 |
| 533 | 83335 | MC | 1348925 | 479914.2 | 520.895 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | 2Q (2) | 146 | NA | NA | 3Q (1.33) | 239 |
| 534 | 83336 | MC | 1348664 | 480103.4 | 514.53 | ONE_LAYER | No | No | 0 | 1Q (4) | 6 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 535 | 83337 | MC | 1346704.28 | 481051.88 | 519.83 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 536 | 83338 | MC | 1346905.77 | 481123.52 | 496.4 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 3 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 537 | 83339 | MC | 1346810.31 | 480752.85 | 523.635 | ONE_LAYER | No | No | 0 | NA (NA) | NA | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 538 | 83340 | MC | 1347503.85 | 481508.65 | 508.76 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 1 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 539 | 83341 | MC | 1347177.78 | 481893.2 | 525.05 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 2 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 540 | 83346 | MC | 1347123.26 | 480617.56 | 523.39 | ONE_LAYER | No | Yes | 1 | 1Q (4) | 5 | NA | NA | NA | NA | 3Q (1.33) | 239 |
| 542 | FMPC-OAB | MW | 1349127.76 | 482174.5 | | ONE_LAYER | Yes | Yes | 1 | 1Q (4) | 8 | NA | NA | NA | NA | 3Q (1.33) | 239 |

*Sample Elevation*
Approximate elevation at which sample measurements are collected.
*Vertical Zone*
Designated aquifer horizon in which well screen is located.
*Protected Status*
Binary flag designating whether or not well is subject to spatial optimization; 1 = protected from optimization, 0 = eligible for optimization.
*Critical Status*
Binary flag designating whether or not well location is statisticall redundant to current network; 1 = critical, non-redundant, 0 = redundant, non-essential.
*Baseline Frequency (per year)*
Approximate current sampling frequency, rounded to nearest quarter; e.g., 3Q = one sample every 3 quarters; per year = number of samples collected per annum.
*Baseline Interval*
Approximate current sampling interval in days, based on averaging lapsed intervals between distinct sampling events; NA = not enough data to compute.
*Well-Specific Optimal Frequency (per year)*
Approximate optimized sampling frequency, rounded to nearest quarter; e.g., 3Q = one sample every 3 quarters; per year = optimal number of samples collected per annum.
*Well-Specific Optimal Interval*
Approximate optimized sampling interval in days, based on either iterative thinning or temporal variogram range; NA = not enough data to compute.

# GTS New Location Report

## Summary of Suggested New Well Locations

Project = fernald_100217
AFIID/Site = FERNALD/FS
Date Completed = August 5, 2010
Author = MacStat Consulting, Ltd/Kirk Cameron

| Easting | Northing | Search Radius | Wells Within Radius | Quantile Score | CV Score |
|---|---|---|---|---|---|
| 1349525.071006 | 470556.850457 | 1123.625921 | 0 | 0.878649 | 0.338684 |
| 1347879.59064 | 473025.071006 | 1123.625921 | 0 | 0.863644 | 0.221462 |
| 1348702.330823 | 480429.732651 | 1123.625921 | 0 | 0.840649 | 0.215743 |
| 1348702.330823 | 482075.213017 | 1123.625921 | 0 | 0.805863 | 0.206552 |

*Search Radius*
Radius of uncertainty search.
*Wells Within Radius*
Number of current wells located within search radius distance of proposed location.
*Quantile Score*
Estimated average percentile of site concentrations within search radius distance of proposed location.
*CV Score*
Estimated average coefficient of variation within search radius distance of proposed location.

## Appendix E. Paducah DoE Site GTS Evaluation

This appendix includes a summary evaluation of GTS when applied at the Paducah, Kentucky DoE site, submitted by a site analyst employed by DoE.

### GTS EVALUATION AT PADUCAH BY INDEPENDENT SITE ANALYST

Geostatistical Temporal-Spatial (GTS Software)

Evaluation of GTS in General and Paducah Groundwater Case Study

May 12, 2010

John Quinn, Argonne National Laboratory

#### 1. Usability of the GTS software

**— How would you describe and rate general usability, including ease of use**

The overall ease of use is good, as familiarity with the 5 main modules and their underlying windows comes fairly quickly. Actually, I have not explored the fifth module (Predict). However, as is mentioned below in the User's Guide discussion, it is not always clear what GTS is doing in each step.

**— Installation and set-up issues, including data import and accessibility**

Installation should be easy for users with administrative privileges on their computers. For users without administrative privileges, installation can require significant intervention by a network administrator.

Installation of multiple builds may cause problems. In my situation, two versions of the supporting program R were present (2.9.1 and 2.10.1). I deleted the older version (required administrator intervention), but then when GTS was opened, it couldn't find R. A deletion and re-install by the administrator was then needed.

**— User interface and navigation issues**

None.

**— Helpfulness of the User's Guide in navigating and understanding GTS**

The manual has been refined over the last half year and is in good shape. It is light on details, however. A companion guide that documents the math/stats involved in the various steps is recommended.

### — GTS saving and reporting capabilities

No problems with saving projects. Not sure what is meant by “reporting capabilities”.

### — GTS graphics capabilities

An issue with the use of GTS on my desktop computer is that when GTS generates maps (shapefiles and/or data points), the legends include the symbols, but do not include the words (the descriptions are blank). This is true for the Tinker example files as well as the Paducah files. Work was performed using the XP SP2 operating system on a new 64-bit machine. Running in compatibility mode (XP, 2000) and reducing screen resolution had no effect.

The legend problem did not occur while running GTS on a much older 32-bit laptop using the XP operating system. So, a lingering problem that could affect many other uses is that the map legends are incomplete, and the maps are therefore impossible to understand. The problem appears to be due to the use of a 64-bit machine. The problem could also be tied to a font issue, but I don't know how to resolve that.

The work-around is to run a large analysis such as Paducah on the faster desktop with files in a particular location (e.g. c:\paducah), then move the files to the same location on the slower laptop to view the mapped results.

### — Encountered bugs, glitches, or other problems

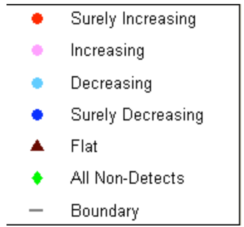
Bugs and crashes were common in earlier builds, but the only known problem while analyzing with GTS using the 15March2010 version is the map legend issue described above. Earlier recommendations for clarifications to the manual have been made to improve its usefulness.

Keyboard shortcuts for cut/copy/paste (Control-X,C,V) do not work for highlighted material in GTS windows. Instead, the user needs to know to right-click and choose Copy. Working keyboard shortcuts are recommended.

### — Suggested improvements/refinements

It would also be helpful if the use had control over

- the colors and styles of shapefile features
- the symbols used in a map (some are hard to notice when plotted on a detailed shapefiles)
- colors and symbols used on maps. I’m colorblind, and in the Trend Behavior Map legend for example, I can’t tell the color for Increasing apart from the color for Decreasing:




GTS needs a means for exporting results, especially maps, for use in reports or presentations. The only current option is doing a screen snap, without control of the image resolution.

Maps created by GTS do not always have consistent spacing along the easting and northing axes, leading to distorted views. If the map window is re-sized, distortion occurs. The map displays should always have consistent easting and northing spacing.

In the Explore module, Concentration Distribution Post-Plots by COC, the legends do not include the 90-100% decile. This analysis is for all aquifers lumped together.

In the Explore module, the legend for Reg. Limit Exceedance Rate includes groupings 10-20, 20-30, …, 90-100. I assume these are percentages. The legend should make it clear by including "%" by each grouping. The 0-10 grouping needs to be added. This analysis is for all aquifers lumped together.

Near the end of the Explore module is the option to choose between analysis of all data together (2D) and data separated by aquifer (2.5D). However, all prior screens consider the data in bulk. Therefore, analysis of outliers and COC statistics do not consider the fact that different populations may be represented. Of course, a work-around is to do separate GTS analyses, each with only the data from a given aquifer, but since the 2.5D option is available, it may make sense to set it near the beginning of the GTS analysis.

In the Baseline step, the Trend Maps and Summary Reports section, Trend Behavior Maps, the mapping provides COC trend maps for three various time periods.

a) Consider allowing user-specified trend time periods, e.g. last xx years, last xx events.
b) Note that the legend includes "Surely Decreasing", but does not include "Surely Increasing"

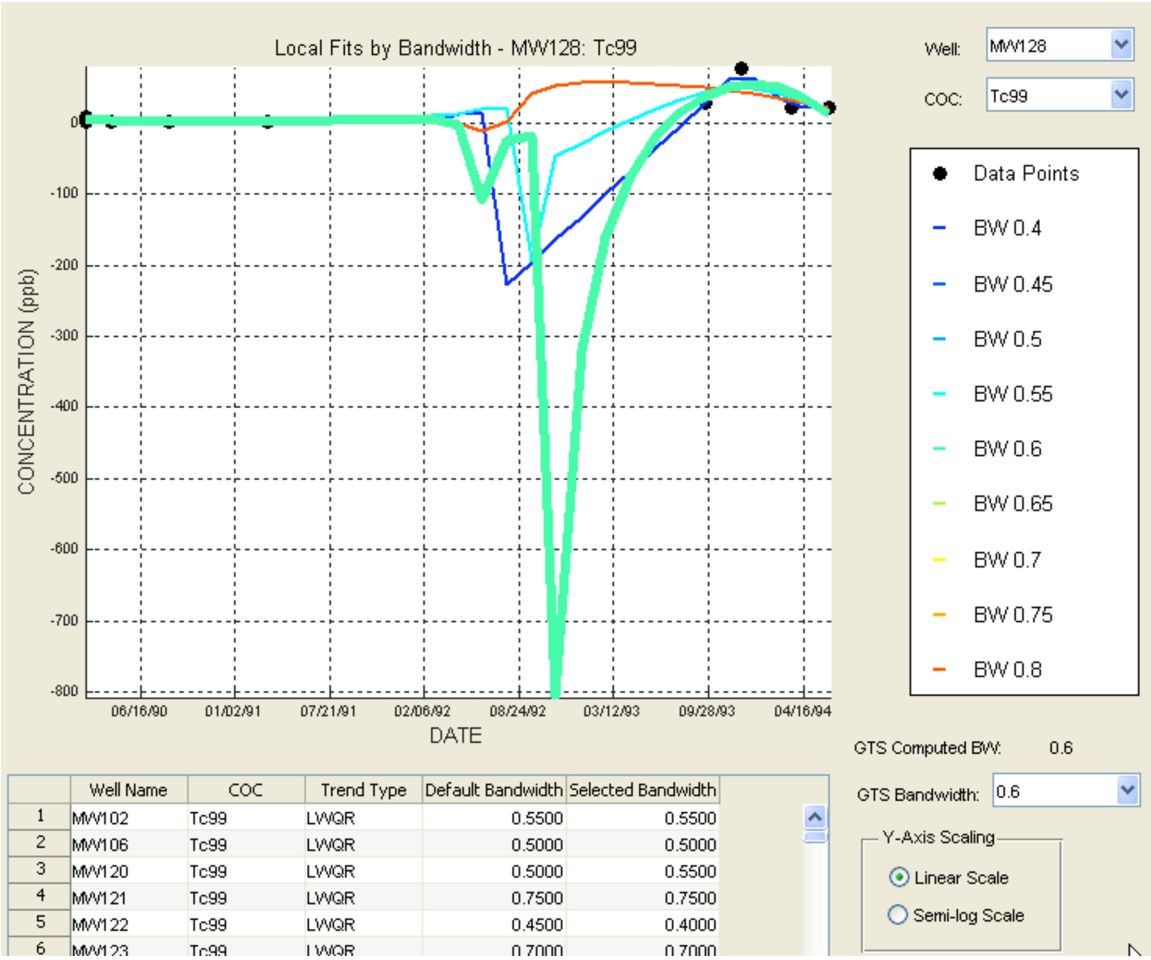
In the Baseline step, the spatial bandwidth choices range from 0.1 to 0.65. I assume the user is to inspect the plotted results to select the bandwidth that provides the most midrange data.

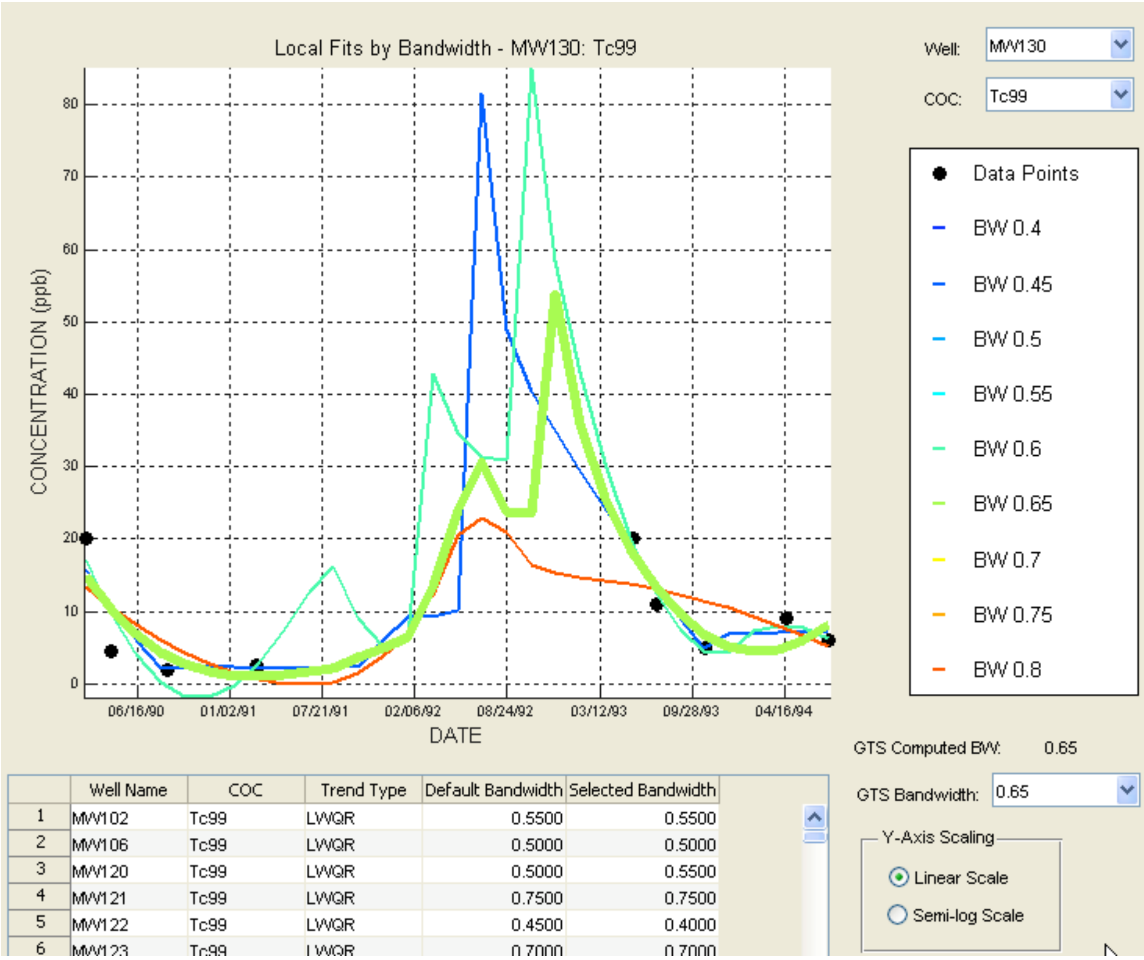
a) Note that the legend includes "Low, Lower, Lowest" for the underestimates, but only includes "High, Higher" for the overestimates. "Highest" is missing.
b) There doesn't seem to be an explanation or a means of adjusting these bins. In addition, while the underestimates are shades of blue and the overestimates seem to be yellow, red, and something for Highest, the Midrange value is kinda hard for me to distinguish (colorblindness). Maybe gray or black, or a different symbol?

In the Baseline step, plots generated using Check Trend Fits by Bandwidth include a 90% Confidence Band. However, much less than 90% of the data plot within this band. Is this an error?

In the Baseline step, time series plots generated with LWQR trends

a) show bizarre behavior between samples, arching wildly high or low (including large negative values). This sort of artifact could have a significant detrimental effect on later GTS calculations. See two examples below.
b) Of my two COCs, only one (Tc99) is available in the pull-down menu.






| | Well Name | COC | Trend Type | Default Bandwidth | Selected Bandwidth |
|---|---|---|---|---|---|
| 1 | MW102 | Tc99 | LWQR | 0.5500 | 0.5500 |
| 2 | MW106 | Tc99 | LWQR | 0.5000 | 0.5000 |
| 3 | MW120 | Tc99 | LWQR | 0.5000 | 0.5500 |
| 4 | MW121 | Tc99 | LWQR | 0.7500 | 0.7500 |
| 5 | MW122 | Tc99 | LWQR | 0.4500 | 0.4000 |
| 6 | MW123 | Tc99 | LWQR | 0.7000 | 0.7000 |

Optimal maps show log-scale color-coded scales of concentration (it can be assumed) and the difference in concentration. The units should be posted on the map.

Network adequacy maps show either one circle or two concentric circle at each point in the mesh. It is unclear from the legend what these represent; in fact, the legend contains a large blank area. The user's guide indicates that they are sized relative to the COV of each COC. It would be helpful to color-code them so that the user can understand which COC is driving a decision regarding adequacy. Also, the Proposed New Location which appears in the user's guide's legend did not show up in my legend, nor did Existing Well Location.

Minor point: For the name of the software, the manual cover uses a "/" between temporal and spatial, while on page 1, a "-" is used. Be consistent. The "-" may be more appropriate.

## 2. Case study report: Paducah

**— Electronic files including a saved project file and electronic (HTML/XML) versions of each of the GTS intermediate and final reports from the analysis**

Three files of input data were created from a Paducah database:

- Tc99 fixed coords.txt [Tc-99 data]
- TCE fixed coords.txt [TCE data]
- WL combo 4 GTS.txt [water level data]

These were imported into one GTS project:

- pad work 051010.gts
- pad work 051010.mat
- testing pad with 031510.db

The original database has 357 wells (MWs, EWs, PZs, others). Of these, 292 have XY, ground surface elevation, screen depths, and Tc-99 data, while 296 wells have XY, ground surface elevation, and screen depths. These wells were used in the case study. The study is focused on three aquifer zones: the surficial aquifer, the regional gravel aquifer (RGA), and the McNairy Formation bedrock. Other wells were dropped from the case study because the database did not include their ground surface elevations, therefore screen depths could not be determined. Some also lacked chemical data. A total of 63 wells have ground surface elevations and screen depths, but no XY coordinates. They are not useable without this spatial information. Many of them also did not have chemical data. One well, MW397, has its XY coordinates switched in the database. This was repaired in the data file prior to working with GTS.

**— A completed cost-savings file based on exporting results from GTS analysis and importing them into the cost-savings spreadsheet**

Did not attempt this because of unknown costs.

**— Write-up of observations/notes regarding the case study analysis, particularly any problems or questions encountered**

See above for discussion on problems noticed.

Default values were used throughout the case study. The effect of tweaking the input was not evaluated, in part because of the long run times (on the order of 5 hours) associated with certain steps of the GTS process on a new 3 GHz machine.

**— Summary of case study optimization findings**

Interestingly, the optimized network maps by COC and aquifer show redundant wells in very close proximity to essential wells (makes sense), but also shows tight clusters of essential wells without redundant wells. I realize there may be a scale issue, or perhaps some adjacent essential wells have significantly different contaminant history. GTS lacks the ability to allow a user to click on a well and learn its name or other information.

GTS identified 2-3 new well locations for each of the 3 aquifers. Some of these locations are in very close proximity to existing wells. It is therefore unclear why these locations were selected. GTS lacks the ability to allow the user to click on existing wells to learn their name or to see their supporting data; it is possible that high fluctuations among existing wells cause GTS to want to place a new well there.

**— Usefulness of GTS in performing the optimization**

I am uncertain of the usefulness of GTS. I am curious as to what other case studies have turned up. While GTS has limitations and can be improved (as discussed above), the run times associated with analyses can be significant. For a simple case with one COC, one aquifer, and one time slice, a sensitivity of bandwidth and other factors could be achievable; however, with multiple COCs, multiple aquifers, and multiple time slices, the influence of non-default parameters cannot feasibly be determined.

GTS' ability to do time series graphs that include a clear means of illustrating non-detects is a very useful tool for manual inspection of monitoring data. A comprehensive analysis of data could lead to a strong understanding of site data and could give a strong indication of which wells should be sample less (or more) frequently, which are redundant, and which areas have uncertainty and could use additional wells. GTS is meant to address these points, but is somewhat of a black box approach at this point.

I have not evaluated these data sets with other software, such as Visual Sampling Plan (VSP), which has overlapping capabilities. But a comparison of results, run times, etc. may be very worthwhile in guiding future development of GTS.